AN INFORMATION FRAMEWORK FOR FACILITY OPERATORS

199[illegible]

JAMES P. BECKETT

NPS

The Pennsylvania State University

The Graduate School

AN INFORMATION FRAMEWORK FOR FACILITY OPERATORS

A Thesis in

Civil Engineering

by

James P. Beckett

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

August 1991

We approve the thesis of James P. Beckett.

Date of Signature

Victor E Sanvido

June 14, 1991

Victor E. Sanvido
Assistant Professor of
Architectural Engineering
Thesis Advisor

Jack H. Willenbrock

June 15, 1991

Jack H. Willenbrock
Professor of Civil Engineering

Francois Grobler

June . 4 . 99

Francois Grobler
Assistant Professor of
Architectural Engineering

A Scanlon

June 17, 1991

Andrew Scanlon
Professor of Civil Engineering
Acting Head of the Department of
Civil Engineering

ABSTRACT

This thesis identifies the information needs of the facility operator and provides an organizational framework to access this information. The "facility operator" is defined as the entity responsible for operating and maintaining the materials, components, and systems which comprise the building but not the furniture, moveable equipment, or manufacturing equipment contained therein.

The building information most useful to the operator was obtained from interviews with staff members of the Maintenance and Operations Division at a large university. The Facility Operator's Information Framework (FOIF) was developed to provide a means of organizing and accessing the information. The FOIF uses five codes: System (mechanical, electrical, structural, plumbing, and architectural), Level (building, floor, room, and component), Vantage (plan, elevation, section, etc.), Index (the Uniform Construction Index), and Information (nine information categories related to the facility). The first four describe building components spatially and functionally. The last code is used to identify the needed information.

A case study was used to test the FOIF. The study considered fifteen work assignments in a representative building and showed the FOIF to be effective in locating the information needed for each assignment.

The primary application for this research is in the development of computer based information systems to support building operation and

maintenance personnel, essentially by giving them on-line access to drawings and other information from the design and construction phases.

(25) * Facilities, * Operators (Personnel), * Maintenance equipment, Information systems.

TABLE OF CONTENTS

LIST OF FIGURES x
LIST OF TABLES xii
ACKNOWLEDGEMENTS xiii

Chapter 1: INTRODUCTION 1
1.1. Background 1
1.1.1. The Facility Operator 2
1.1.2. Operations Scenario 2
1.1.3. Current Practice 3
1.2. Problem Statement 4
1.3. Research Objectives 4
1.4. Research Significance 5
1.5. Methodology 6
1.5.1. Review of the Literature 6
1.5.2. Identification of Information Needs 6
1.5.3. Framework Definition 7
1.5.4. Testing of the Model with a Case Study 8
1.6. Summary and Thesis Outline 9

Chapter 2: LITERATURE REVIEW 10

2.1. Overview 10

2.2. Facility Operations 10

2.2.1. Facility Operations: Part of the Facility Life Cycle 11

2.2.2. The Facility Operator's Primary Job: Maintenance 11

2.2.3. Information Requirements 14

2.3. Information Classification Systems 16

2.3.1. The SfB System 16

2.3.2. The Universal Decimal Code (UDC) System 17

2.3.3. The Uniform Construction Index (UCI) 17

2.4. Product Models 18

2.4.1. General AEC Reference Model (GARM) 18

2.4.2. The RATAS Model 21

2.4.3. Project Developers Information Framework 23

2.4.3.1. The Product Model Architecture (PMA) 23

2.4.3.2. Classification and Coding Structure 23

2.4.4. Other Systems 26

2.5. Summary 28

Chapter 3: FACILITY OPERATOR INFORMATION REQUIREMENTS: A LARGE OWNER'S VIEW 29

3.1. Overview 29

3.2. The Maintenance and Operations Division 29

3.2.1. Organizational Structure 30

3.2.2. Facility Maintenance Trades 30

3.2.3. The Trade Supervisors 31

3.3. Scope of the Interviews 31

3.4. Results of the Interviews 31

3.4.1. Explanation of UCI Index Codes 34

3.4.2. Explanation of Level Codes 41

3.4.3. Explanation of Information Sources 41

3.5. Observations Based on Interviews 42

3.5.1. Time Critical Information Requirements 42

3.5.2. Overlapping Lines of Responsibility 43

3.5.3. Reliance on Experience and Inspection 44

3.6. Consolidation of the Information Needs 44

3.7. Requirements for Organizing the Information 47

3.8. Summary 48

Chapter 4: THE FACILITY OPERATOR'S INFORMATION FRAMEWORK (FOIF) 50

4.1. Overview 50

4.2. Criteria Used for Developing the FOIF 50

4.3. Overview of the FOIF 51

4.4. The FOIF Coding Structure 52

4.4.1. Building Systems ("System") 52

4.4.2. Building Levels ("Level") 55

4.4.3. Geometric Vantage Point ("Vantage") 57

4.4.4. UCI Code ("Index") 57

4.4.5. The Information Code ("Information") 60

4.5. Using the FOIF 60

4.5.1. Retrieving Information 61

4.5.1.1. Using the System Code 61

4.5.1.2. Using the Level Code 61

4.5.1.3. Using the Vantage Code 62

4.5.1.4. Using the Index Code 62

4.5.1.5. Using the Information Code 62

4.5.2. Storing Information 63

4.6. Summary 63

Chapter 5: CASE STUDY 64

5.1. Overview 64

5.2. Agricultural Science and Industries Building 64

5.3. Description of the Work Assignments 65

5.4. Case Study Illustration and Results 66

5.4.1. Illustration of Cases 4 and 13 66

5.4.2. Tabular Listing of Results 72

5.5. Findings from the Case Study 78

5.5.1. Need for More "System" Codes 78

5.5.2. Multiple Coding Structures for the Same Item 78

5.6. Discussion 79

5.7. Summary 80

Chapter 6: CONCLUSIONS 81
6.1. Overview 81
6.2. Comparison of Research with Objectives 81
6.2.1. Defining Facility Operations and Information Organization 82
6.2.2. Identifying Facility Operator's Information Needs 82
6.2.3. Defining an Information Framework 83
6.2.4. Testing the Framework 83
6.3. Limitations of the FOIF 84
6.4. Areas for Further Research 85
6.4.1. Testing on Other Owners 85
6.4.2. Integration with the Other Life Cycle Phases 85
6.4.3. Development of Standard System Codes 86
6.4.4. Implementation of the FOIF 87
6.5. Summary and Conclusion 88

BIBLIOGRAPHY 90

Appendix A: INTERVIEW QUESTIONNAIRE 93
Appendix B: MAINTENANCE AND OPERATIONS DIVISION 95
ORGANIZATIONAL CHART 95
Appendix C: SAMPLE INTERVIEW QUESTIONS AND RESPONSES 98

LIST OF FIGURES

Figure 2.1 Relation of Facility Operations to the Facility Life Cycle in the IBPM 12

Figure 2.2 Illustration of UCI Division, Broadscope, and Narrowscope Titles 19

Figure 2.3 Illustration of the RATAS Model 22

Figure 2.4 Khayyal's Product Model Architecture 24

Figure 2.5 Khayyal's Classification and Coding Structure 25

Figure 2.6 Example of a Work Breakdown Structure 27

Figure 3.1 Consolidation of Information into Categories 45

Figure 4.1 The Facility Operator's Information Framework (FOIF) 53

Figure 4.2 Building Level Structure 56

Figure 4.3 Geometric Vantage Points, Two and Three Dimensional 58

Figure 5.1 Example of Frame for Case 4: Room 1211 Lighting Plan 68

Figure 5.2 Example of Frame for Case 4: Room Fixture Schedule 69

Figure 5.3 Example of Frame for Case 4: Lighting Fixture Schedule 70

Figure 5.4 Example of Frame for Case 13: Room 3132 Architectural Plan 71

Figure 5.5 Example of Frame for Case 13: Room 3132, North Elevation 73

Figure 5.6 Example of Frame for Case 13: Accessory Schedule 74

LIST OF TABLES

Table 3.1 Interviewees and Subjects Discussed..32
Table 3.2 Compiled Interview Results..35
Table 5.1 Case Study of FOIF on Fifteen Work Assignments....................75

ACKNOWLEDGEMENTS

I would like to thank all of the many people who have helped me with this research effort. In particular, I am indebted to:

Dr. Victor Sanvido: for many fresh ideas and valuable insights. Your outstanding leadership, guidance, and friendship are truly appreciated.

Drs. Willenbrock and Grobler: for serving on my thesis committee. Your wisdom, dedication, and valuable comments were a tremendous help.

The CIC Research Team: for camaraderie, friendship, and constructive criticism. I am especially grateful to Greg Perkinson for providing valuable feedback along the way.

The Pennsylvania State University's Office of Physical Plant, Maintenance and Operations Division: for supporting this research effort. In particular, I would like to thank Mr. Ed DeBrasky for all his unselfish and tireless support.

The United States Navy: for affording me the time and resources to partake in this fine learning opportunity.

Most importantly, I would like to thank my wife, Sandy, and my children. Words alone cannot express my overwhelming gratitude for all of your patience, support, and love. Thank you so much.

Chapter 1

INTRODUCTION

1.1. Background

Providing a facility is a long and complex undertaking. It starts with the idea to construct the facility. Subsequently, the initial concept has to be defined and communicated by way of a design. When the facility is constructed, design details and specifications must be transformed into an actual facility, which then must be operated. Years later, when the facility is no longer serviceable or required, it is demolished and the life cycle is ended.

To support the various life cycle phases between the conception of a facility and its eventual demolition, much information must be created and communicated. To the designer, it is important to know the owner's requirements. To the builder, knowing the details of what the designer intended, and what the finished product should look like, is important. To the facility operator, a detailed knowledge of the as-built facility is essential.

1.1.1. The Facility Operator

The facility operator, or building superintendent, is the person responsible for operating and maintaining the building's architectural, structural, civil, mechanical, electrical, and plumbing systems and their subsystems. This operator may be assisted by a staff dedicated to that facility; a staff that collectively supports all facilities in a location; or by contract personnel. The operator is responsible for all systems and components in the building. He is generally not responsible for furniture, moveable equipment, or manufacturing equipment. The operator's role is defined in greater detail in Chapter 2.

The facility operator has tremendous information needs, particularly when first taking occupancy of a new building. He must learn how to operate systems and develop maintenance schedules for major pieces of equipment, arrange and budget for janitorial services, fix components when they break, and do everything else required to keep the facility operational. This study concentrates on the information required by the facility operator to effectively provide a facility to the user.

1.1.2. Operations Scenario

To help illustrate the information needs of the facility operator, a typical situation is presented. Consider a water leak in an office ceiling. Some of the many questions the operator might ask are:

Where is the office within the building?

Is it on the top floor, such that water could be leaking from the roof?

Does the office have an exterior wall?

What plumbing is above the ceiling or nearby?

Of what material are the pipes made?

Where are the nearest isolation valves?

What is the ceiling type?

Is the area above the ceiling accessible from the office?

Many information sources might exist which could provide answers to the above questions. On-site inspection, as-built drawings, contract specifications, and manufacturer literature are but a few. But which are most useful? More importantly, how should they be organized to most effectively provide the answers to the facility operator's questions? These are two important questions which lay the foundation for this thesis.

1.1.3. Current Practice

During the earlier phases of a facility, large amounts of information are created. When planning and designing a facility, product models are sometimes used to help organize information by describing the facility in terms of its parts. Design and construction phases make use of similar models. They also use classification systems such as the Uniform Construction Index (UCI) to describe materials, systems, and components of the building and to correlate plans with specifications.

Upon completion of the construction phase there is generally a transfer of information to the facility operator. The quantity and format of the information delivered, however, varies widely. Sometimes the operator is provided with a complete set of electronically stored documentation and as-built CAD (computer aided design) drawings. Other times the operator is given little more at the ribbon-cutting ceremony than a set of keys.

Regardless of the information provided, the facility operator must provide the user with an operational building. Many computer systems and software exist to help the operator. Newer systems on the market can help predict future requirements for maintenance and repairs of major components. Other systems monitor things like operating temperatures, pressures, and electrical loads and can adjust each one by centrally operating the necessary controls. Still other systems exist to automate preventive maintenance planning and scheduling and to coordinate responses to facility problems.

1.2. Problem Statement

Despite the availability of product models, classification systems, and computer software packages, there is no readily available, common framework for organizing the information required to operate a facility so that it may be readily accessed by the facility operator.

1.3. Research Objectives

To address the stated problem, four objectives are proposed. They are:

1. To define the role of the facility operator and identify methods available for organizing information used to describe facilities and their parts.

2. To identify which information about buildings is most useful to the operator and determine the sources for that information.

3. To define a simple, logical, and adaptable framework for organizing and accessing information used by the facility operator.

4. To test the framework with a case study.

1.4. Research Significance

The value of this thesis is that it

1. Provides a guideline the owner can use to specify information the designers, vendors, and contractors must deliver to the operator;

2. Provides a logical system for organizing and accessing information to improve the facility operator's effectiveness;

3. Provides a basis for future development of automated data acquisition and storage systems to support facility operations.

1.5. Methodology

The following methodology was used to meet the objectives of the study:

1.5.1. Review of the Literature

The literature was reviewed to define the role of the facility operator and identify the basic types of information used to operate facilities. The literature was also used to identify methods of organizing information in the architectural, engineering, and construction (AEC) industry.

1.5.2. Identification of Information Needs

The Pennsylvania State University, a large, multi-facility owner with a knowledgeable facility operations staff was studied. By selecting an owner with several facilities, broader types of information applicable to a variety of buildings could be obtained.

Interviews were held with individuals knowledgeable in their respective trades. These individuals did not actually perform the work; instead, they managed the work crews and were responsible fo. providing them with the information and resources needed to perform their jobs. The eleven individuals were briefed as a group on the objectives of the study and provided with a list of questions which would be asked in the interviews (see Appendix A). Thirty-minute interviews were then scheduled and conducted separately over a two-day period. All of the interviewees were cooperative and eager to help with the study. Use of a private conference room was arranged to minimize outside interruptions.

Questions were structured to first identify the various systems managed by the individual (i.e. heating, power distribution, security, steam, etc.). The questions then probed the types and sources of information used to manage each system. An example of the details identified by the interviews was the need for the name of the manufacturer and the color number of paint. This allows easy paint matching when a section of wall is repaired.

After obtaining specific information items needed by each trade supervisor, a more general list of information categories was defined. These categories were broader in definition and were considered applicable to the facility operator in general.

1.5.3. Framework Definition

The Facility Operator's Information Framework (FOIF), a simple framework for organizing and accessing information used by the facility operator, was developed. The coding structure used in the FOIF is based on the selection of information modelling schema found in the literature, the information needs of facility operators obtained in the interviews, and on the author's experience. For simplicity, the fewest possible codes needed to accurately describe building components spatially and functionally were used. Where possible, commonly accepted codes and terms were chosen.

Codes were also designed to be adaptable and expandable to improve the FOIF's longevity. A description of how the FOIF organizes and accesses facility information was prepared.

1.5.4. Testing of the Model with a Case Study

A case study was conducted to test the ability of the FOIF to describe the location of building components both spatially and functionally. A modern, moderately sophisticated office building was selected for the case study. To fully test all aspects of the framework, the building had to have at least two stories; contain plumbing, mechanical, and electrical systems; and be large enough to provide a variety of problems for study (at least 50,000 square feet). The Agricultural Science and Industries Building at The Pennsylvania State University's main campus, a five-story combination office, laboratory, and classroom facility met these criteria and was thus selected.

A listing of recent work assignments (requests for maintenance or repair) for the building was obtained from the University's Facility Maintenance and Operations Division. Starting with the most recent work assignments, fifteen were selected to represent a variety of problem types encompassing each major trade. For each assignment involving the facility, the item (for instance, a faulty light fixture in a specific room) was located in the facility documents (primarily drawings). To test the framework, the FOIF was then used to locate the same item. In each case, the ability of the FOIF to identify the documents which were used is noted.

1.6. Summary and Thesis Outline

This chapter provided an introduction to the study and an overview of facility operations. The chapter identified information organization as the topic of the thesis and addressed a major problem facing facility operators: the lack of a common framework for classifying and defining the information required to operate a facility. A methodology for researching and resolving this problem was then outlined.

Chapter 2 provides a brief summary of the literature relating to the study. It explains facility operations and identifies the general types of information needed to support it. Methods of organizing information in the AEC industry are reviewed.

In Chapter 3, the information needs of facility operators are identified. Chapter 4 defines the Facility Operator's Information Framework (FOIF). The purpose of the framework is to provide a coding structure for organizing and accessing information used by facility operators. Subsequently (Chapter 5), the FOIF is tested with a case study in which actual work assignments for a representative building are used.

Chapter 6 summarizes the study, identifies limitations of the FOIF, and suggests areas for further research.

Chapter 2

LITERATURE REVIEW

2.1. Overview

This chapter explains the function of the facility operator and shows how facility operations fits into the overall life cycle of a building. An overview of several existing classification systems and product models used to organize information about facilities is then provided.

2.2. Facility Operations

This section discusses facility operations in terms of the overall facility life cycle. Maintenance, a major function performed during the operation phase, is explained. Key sources of information required to operate facilities are identified.

2.2.1. Facility Operations: Part of the Facility Life Cycle

The operations phase of a building's life cycle is defined as "all of the activities which are required to provide the user with an operational facility" [Sanvido, 1990, p. (2) 10]. The operations phase is one of several in a building's life cycle. The phases, as defined in the Integrated Building Process Model [Sanvido, 1990, p. (2) 10], are: Manage Facility, Plan Facility, Design Facility, Construct Facility, and Operate Facility. Figure 2.1 shows the relationship of facility operations to the other life cycle phases.

Facility operations is generally the longest and the most costly phase of the entire life cycle, accounting for approximately 85 percent of the life cycle costs [NRC, 1987, p. 59; Smeallie et al., 1987]. It relies heavily upon much of the information generated during project planning, design, and construction.

Arrows are used in Figure 2.1 to represent data entities passed from one phase to the next [Sanvido, 1990, p. (2) 5]. Of particular importance are the arrows shown in the highlighted region which enter the top of the Operate Facility node. These arrows represent facility operations documents, the organization of which is the primary focus of this study. These documents are defined further in Section 2.2.3.

2.2.2. The Facility Operator's Primary Job: Maintenance

The majority of the functions performed by the Facility Operator are referred to in the literature as facilities maintenance. Facilities maintenance

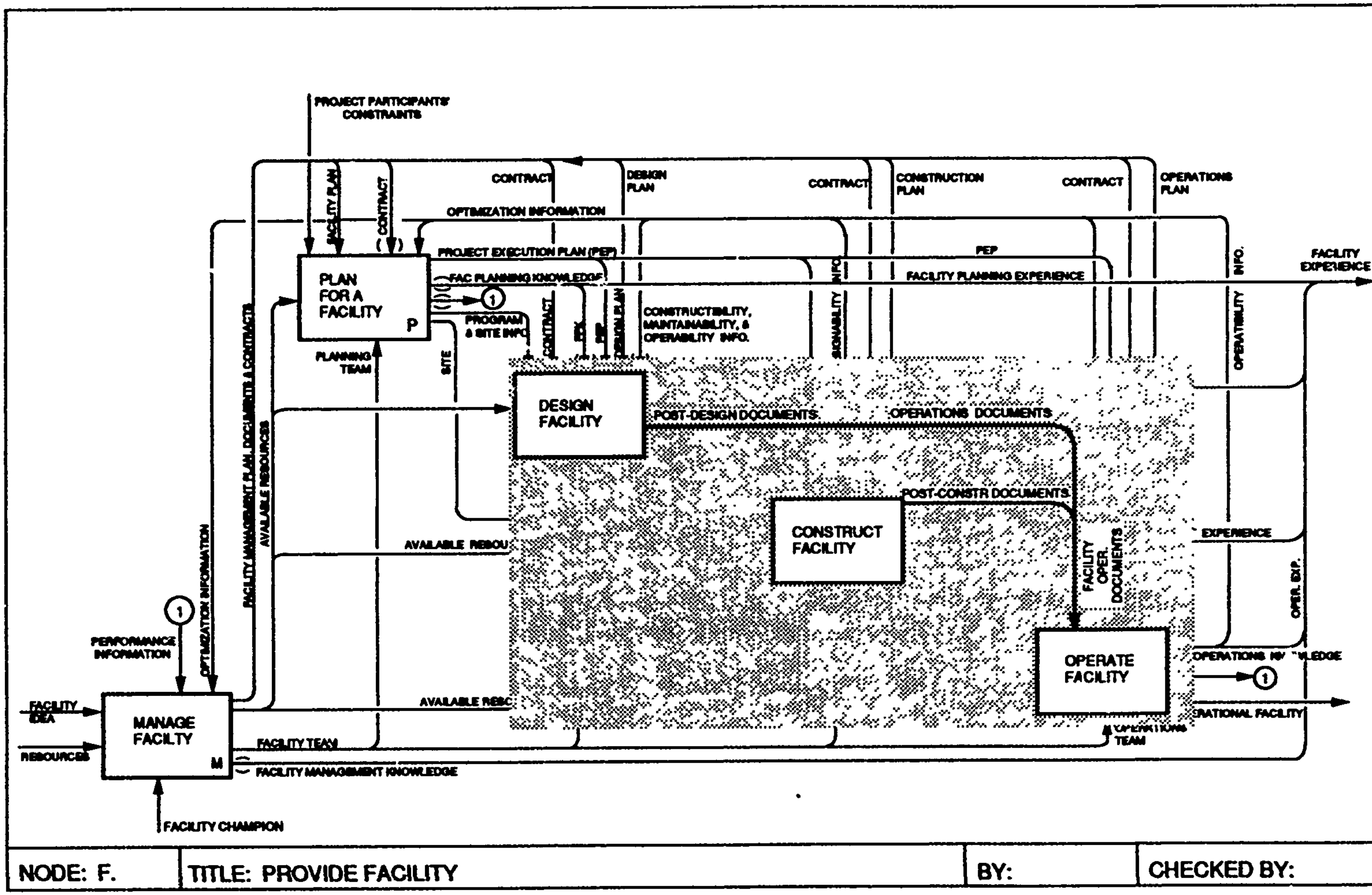


Figure 2.1: Relation of Facility Operations to the Facility Life Cycle in the IBPM [Adapted from Sanvido, 1990, p. (2) 11]

is defined as "the set of ordered activities which, when properly managed, allow for the continual operation of a facility" [Magee, 1988, p. 4].

Facilities maintenance, like construction, can be broken down into direct and indirect activities. The indirect activities are those items needed to administer the direct items. Examples of indirect activities are work identification, scheduling, and purchasing. Direct maintenance activities are those which actually preserve or restore the function of the facility. Though the terminology varies widely in the industry, direct activities can generally be divided into: housekeeping, general maintenance, preventive maintenance, repair, replacement, improvement, modification, and utilities [Magee, 1988]. Since the focus of this study is on maintenance, only the related categories are discussed below:

General Maintenance: General maintenance items are usually accomplished at discrete intervals and include such things as repainting walls and trim, replacing faucet washers, tightening valve gland packings, and lubricating door hinges.

Preventive Maintenance: Preventive maintenance is work performed to an operational device or facility to keep it operating at its proper efficiency without interruption. When preventive maintenance is continually neglected, dramatic and costly failures often occur; thus formal preventive maintenance programs are generally a high priority. Typically, preventive maintenance is performed on expensive pieces of mechanical and electrical equipment like pumps, boilers, chillers, and high voltage switches. Preventive maintenance requirements are usually specified by equipment manufacturers.

Repair: Repair work involves restoring to operation some component of the facility after it has failed. An example might be patching a roof membrane or replacing bearings in a pump or motor. Repair is often referred to as corrective maintenance.

Replacement: Replacement work refers to a program of planned replacement of facility components. It may be further limited to major components such as air conditioning compressors, furnaces, or hot water heaters. Replacement is performed when the equipment has reached the end of its useful life; when it no longer can perform due to degradation of its internal components; or when repair is no longer cost effective. Rebuilding of components is considered replacement. Replacement is another form of corrective maintenance.

2.2.3. Information Requirements

Facility operators need an accurate record of what was designed and built [Howard et al., 1989]. It can be stated that facility operations is controlled, in part, by the availability of facility operating documents [Guvenis, 1989, p. (1) 8]. Guvenis defines operations documents as "The formal documents...for managing, operating, and maintaining the facility" [1989, p. (B) 3]. A description of the common information sources is provided below:

On-site Inspection: Physically inspecting the jobsite includes visual inspections, partial removal of components, and destructive and non-destructive testing. It can provide current, accurate information about a facility but is costly and time consuming. Users default to this method to collect data when it is not readily available from other sources.

Drawings: Facility drawings are a graphic representation of the construction project. They show size and shape, general indication of materials and their location, connections and details, diagrams, and isometrics depicting items such as mechanical and electrical systems. Schedules of structural elements, equipment, and finishes are also part of the drawings [CSI, 1980, p. 2]. As-built drawings show the actual "as-built" conditions after construction.

Specifications: The specifications are the document which contains qualitative requirements for products, materials, and trades [CSI, 1980, p. 2].

Manufacturer literature: Manufacturer literature refers to pages from a manufacturers catalog, technical product specifications, or sales brochures which identify, explain, or quantify a product. These items are commonly referred to as submittals.

Shop drawings: These drawings show the specific details used to fabricate materials. Typical examples include structural steel connections, steel reinforcing bar drawings, and window fabrication details. Shop drawings are also referred to as submittals.

Operation and maintenance manuals: Operation and maintenance manuals are user's guides to start-up, operation, maintenance, and troubleshooting procedures. They are usually furnished with major mechanical and electrical equipment.

2.3. Information Classification Systems

The information sources described in the previous section give the operator details of the many products, materials, and systems which comprise the building. This section describes some of the more common classification systems for organizing this building information.

2.3.1. The SfB System

Developed in the Swedish construction industry in 1948, this international system combines letters and numbers to code items related to the construction operation. There are three parts of an SfB citation: the functional element, the construction, and the material. A sample classification using SfB is: (21) F g2. This stands for wall, brick, clay, or a wall made of clay bricks [Green, 1966].

2.3.2. The Universal Decimal Code (UDC) System

The Universal Decimal Code System (UDC) is similar to SfB in methodology but is based on numerical codes separated by decimal points. The UDC System is broad in scope; construction technology is just one of many areas it classifies. Due to the system's diversification, UDC codes tend to be quite long. For instance, the UDC code for describing a wall made of clay bricks is 69.022.322:691.421 [Green, 1966].

2.3.3. The Uniform Construction Index (UCI)

The Uniform Construction Index (UCI), published by the Construction Specifications Institute and commonly referred to as "Masterformat," is the standard building indexing scheme within the United States construction industry. The UCI is a master list of five-digit code numbers which identify building products, materials, and trades [CSI, 1980, p.2]. The UCI is divided into sixteen major divisions of work. A listing of the divisions follows [CSI, 1978, pp. 8-9]:

1 General requirements
2 Sitework
3 Concrete
4 Masonry
5 Metals
6 Wood and Plastics
7 Thermal/ Moisture Protection

8	Doors and Windows
9	Finishes
10	Specialties
11	Equipment
12	Furnishings
13	Special Construction
14	Conveying Systems
15	Mechanical
16	Electrical

The sixteen UCI divisions are decomposed hierarchically into broadscope and narrowscope titles. Figure 2.2 illustrates this decomposition for different types of unit masonry.

2.4. Product Models

Product models are systems for describing large and complex things, such as buildings, in terms of their more manageable component parts. Within the AEC industry, the structure and format of product models vary widely. Several select product models follow.

2.4.1. General AEC Reference Model (GARM)

Gielingh [1987] initiated this complex model in 1982 as part of an international product model standardization effort. The model serves as a

Division 4: Masonry

Broadscope title: 04200 Unit Masonry

Narrowscope titles:

04210 Brick Masonry
04212 Adobe Masonry
04213 Structural Glazed Tile Masonry
04220 Concrete Unit Masonry
04221 Glazed Concrete Unit Masonry
04222 Exposed Aggregate Concrete Unit Masonry
04223 Split-face Concrete Unit Masonry
04224 Fluted Concrete Unit Masonry
04225 Molded Face Concrete Unit Masonry
04230 Reinforced Unit Masonry

(CONT.)

Figure 2.2: Illustration of UCI Division, Broadscope, and Narrowscope Titles [CSI, 1978]

data-exchange medium for design, production and maintenance information for buildings, systems, and components as well as site work. The core of the model is the five dimensional Product Definition Unit (PDU) which consists of "discriminators" for stage, level, status, role, and type. The discriminators serve to define the following:

Stage: The stage identifies the phase of the facility life cycle to which information pertains.

Level: The level refers to the scope of the information. It is either specific or generic. Specific information is unique and generic information is shared.

Status: The status differentiates among alternatives, typically during the design phase. Three categories are used: Alternative, Selected, and Rejected.

Role: Role differentiates between information about the original product and replacement products.

Type: Type is used to decompose the building into smaller categories called arrangements, assemblies, parts, joints, and form features.

2.4.2. The RATAS Model

The RATAS Model [Björk, 1989] is a building product model which describes a building symbolically using objects, attributes, and classes. A representation of the model is shown in Figure 2.3. Objects are arranged in a hierarchy (left half of the figure). Each object has attributes (lines connecting the left and right halves of the figure) which serve to group objects into classes (right half of the figure). This arrangement is explained further below:

Objects: Objects describe the whole in terms of its parts using an abstraction hierarchy. The five levels of abstraction used in the RATAS model to describe a building functionally are the building, system, subsystem, part, and detail.

Attributes: To each object, a number of attributes can be associated that describe the properties of the object. Attributes can be of many different types. Some of the more important attributes are: numeric values, such as prices; text; pictures or video sequences; codes, such as UCI or SfB; and lists.

Classes: Classes, which are also arranged in hierarchies, group objects based on their attributes. Examples of classes are load bearing structures, partition walls, and doors. Individual objects are a subset of classes.

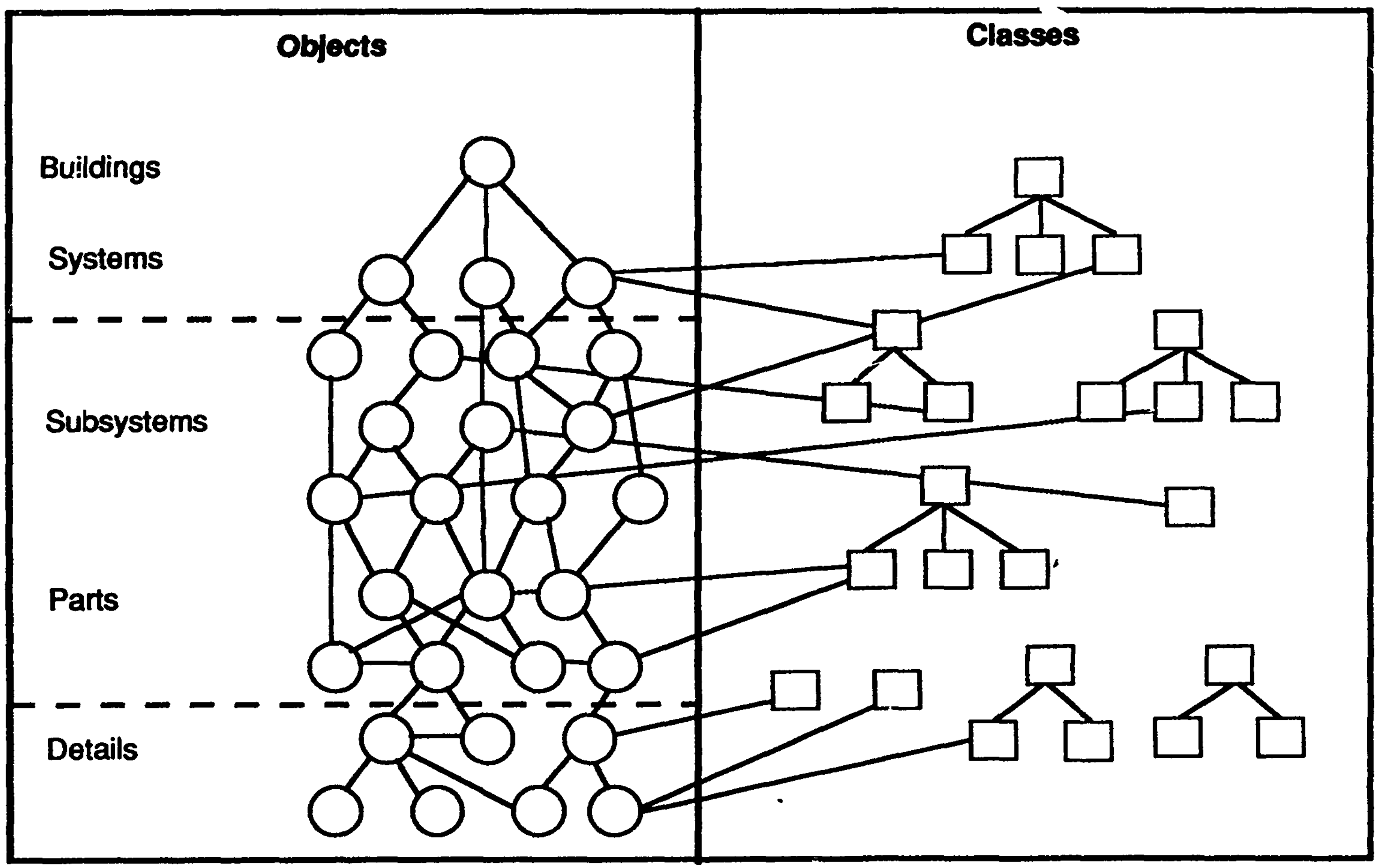


Figure 2.3: Illustration of the RATAS Model [Source: Björk, 1989, p. 73]

2.4.3. Project Developers Information Framework

The Project Developers Information Framework [Khayyal, 1990] consists of a conceptual Product Model Architecture (PMA) for structuring and integrating building information and a coding and classification scheme for storing and retrieving this information.

2.4.3.1. The Product Model Architecture (PMA)

The PMA, illustrated in Figure 2.4, defines two orthogonal categories for structuring information: building levels and discipline breakdown. The building levels refer to the architectural view of a building at increasing levels of detail from the project as a whole down to the individual components. The discipline breakdown refers to the trade or specialty area within the AEC industry. The disciplines defined are: Architectural, Civil, HVAC, Plumbing, Electrical, and Structural.

The relationship between building levels and the discipline breakdown are expressed by attributes. Attributes describe five qualities: function, form, economy, mechanism, and time.

2.4.3.2. Classification and Coding Structure

The Project Developer's Information Framework includes a classification and coding structure to support the PMA. The frame based structure consists of twenty numeric and alphanumeric fields which describe qualities of the facility (see Figure 2.5). Each of the twenty fields has a unique coding scheme.

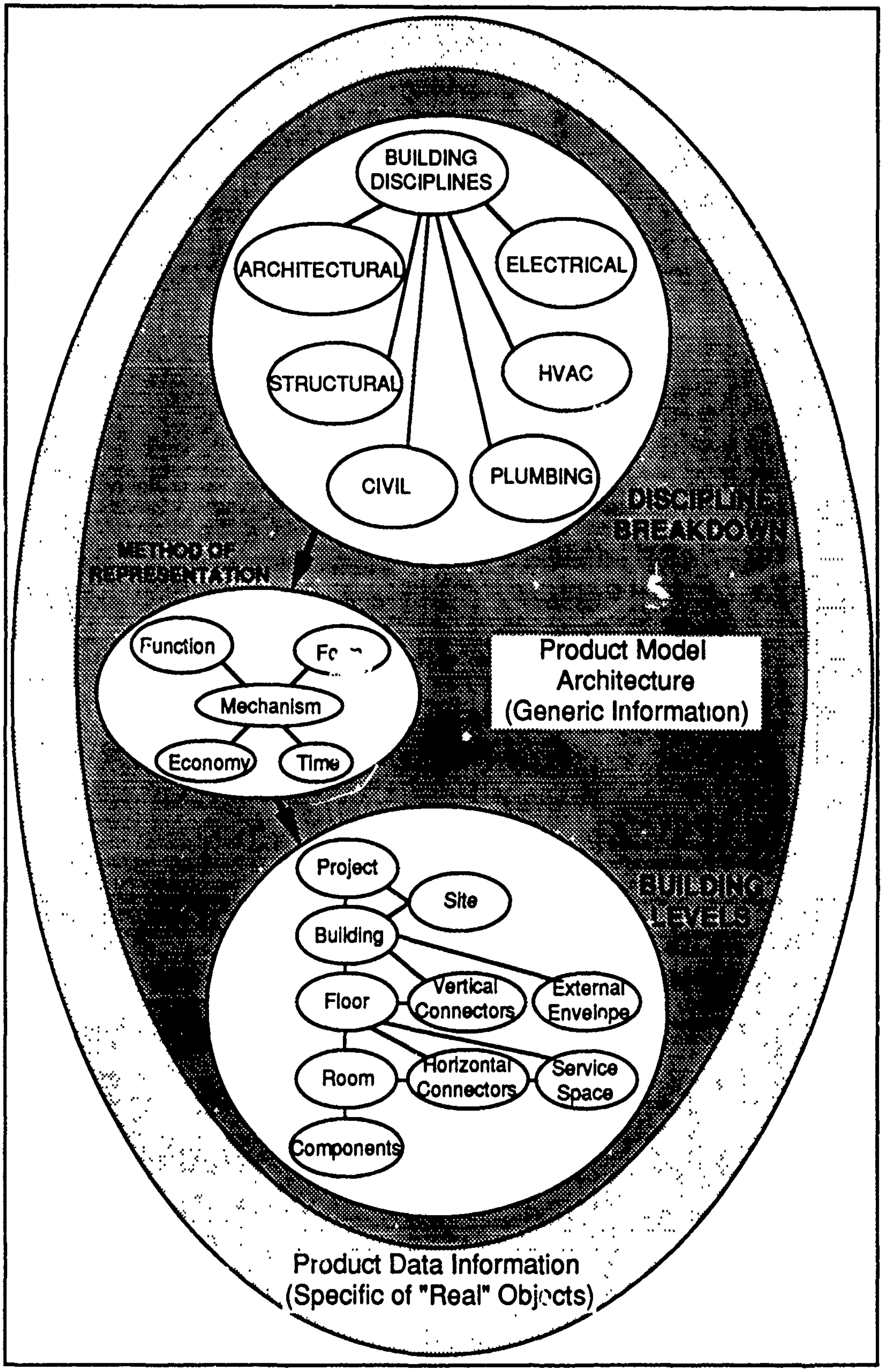


Figure 2.4: Khayyal's Product Model Architecture [Source: 1990, p. 79]

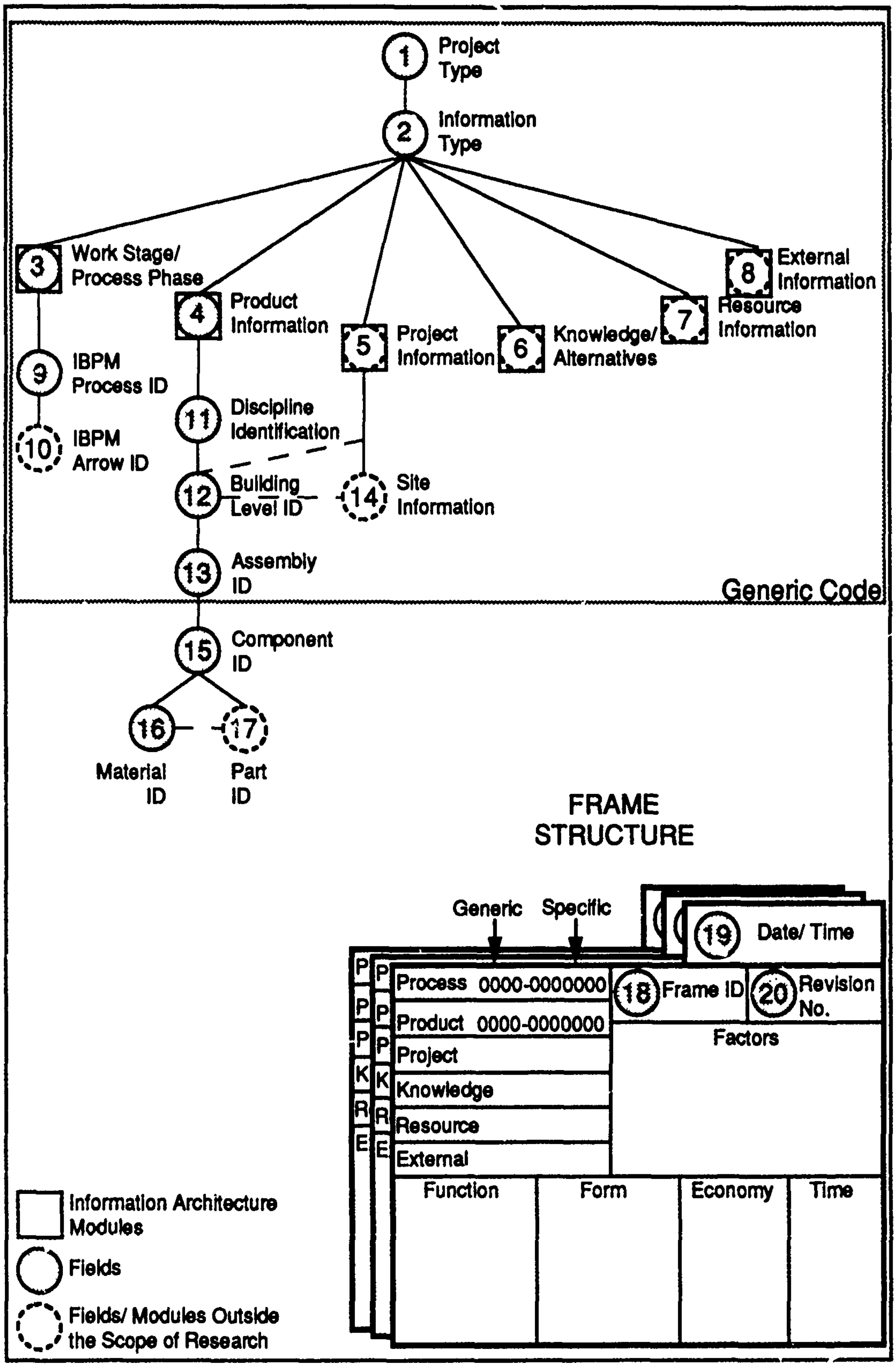


Figure 2.5: Khayyal's Classification and Coding Structure [Source: 1990, p.109]

The first fourteen fields are generic codes. Generic codes refer to such things as the project itself, life cycle phase, discipline identification, building level, and site information. Specific codes make up the remaining six fields. Specific codes identify components, materials, and parts; the frame number; the date and time; and the revision number.

2.4.4. Other Systems

Though it has other uses, the Work Breakdown Structure (WBS) can be applied in the AEC industry as a tool for subdividing large objects into their component parts [Cleland, 1983, p. 50]. The structure of the WBS is hierarchical, such that the bottom level represents detailed information while the top level represents information about the building as a whole [Cleland, 1983, p. 291]. An example of a WBS for a building foundation is shown in Figure 2.6.

Other systems developed for modelling information include Turner's Building Systems Model [Turner, 1989], Martin's Distribution System Model [Martin, 1989], and NIDDESC's Reference Model for Ship Structural Systems. Turner's model is broad, encompassing buildings, ships, process plants, civil projects, and space habitats. Martin's model pertains to shipboard distribution systems. The NIDDESC model pertains to ship structural systems. These models are similar to other product models in that they decompose something complex into terms of more manageable parts. A summary of each can be found in Khayyal's paper [1990].

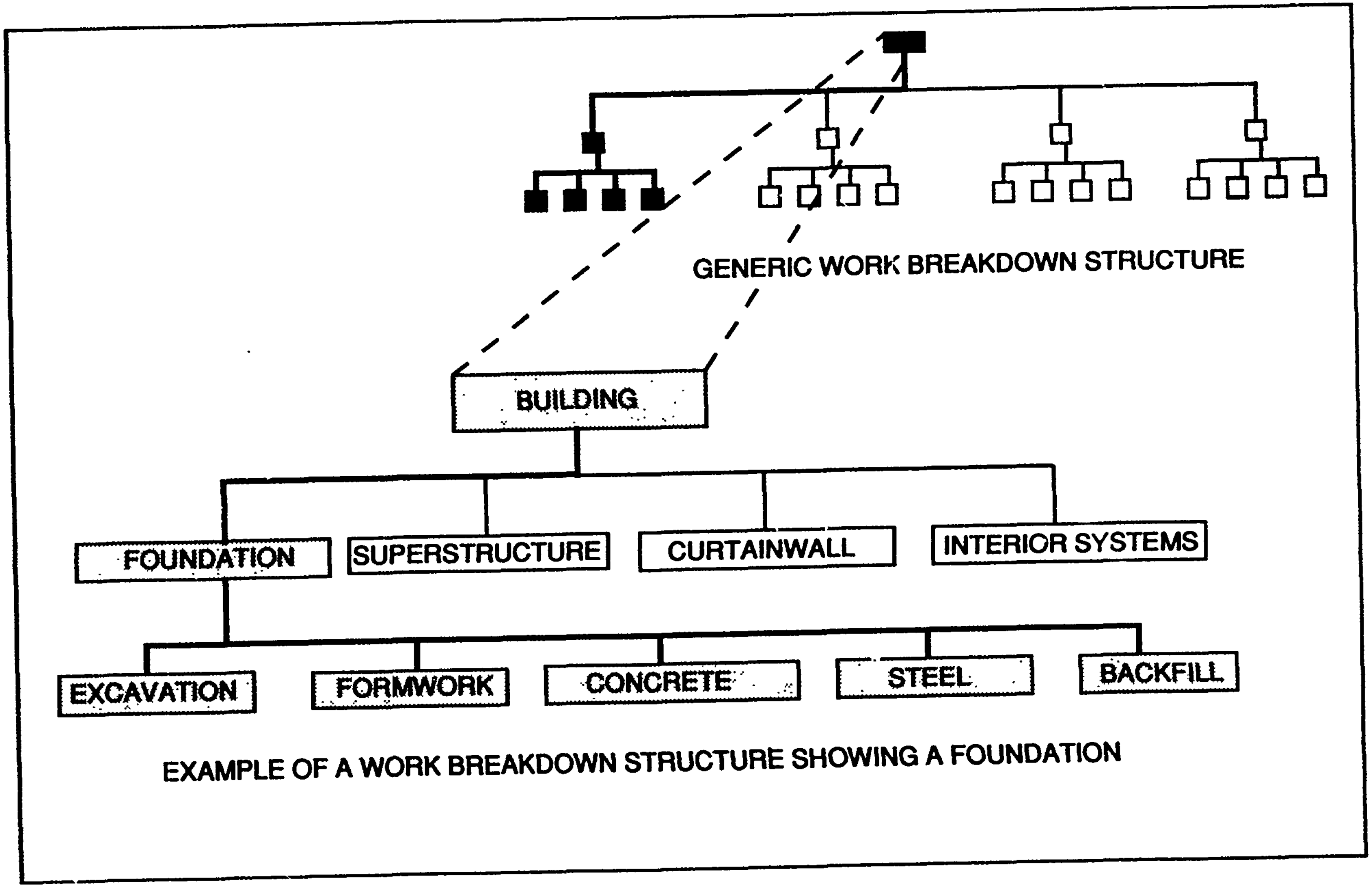


Figure 2.6: Example of a Work Breakdown Structure [Cleland, 1982]

2.5. Summary

This chapter defined and explained the role of the facility operator. Existing systems for organizing and coding information about materials used in buildings were identified, and several common product models were surveyed.

Chapter 3

FACILITY OPERATOR INFORMATION REQUIREMENTS: A LARGE OWNER'S VIEW

3.1. Overview

The purpose of this chapter is to identify the information needs of facility operators. Interviews were conducted with supervisors representing each facility trade on the maintenance and operations staff at a private, non-profit, multi-facility institution. The interview results were compiled and identified many specific information items found useful in each of the various trades. Finally, a generalized list of nine information categories applicable to facility operators was defined.

3.2. The Maintenance and Operations Division

To determine the information needs of facility operators, The Pennsylvania State University, a large, multi-facility owner with an experienced operations staff was selected. It operates more than 300 buildings totalling 12.4 million square feet at its University Park Campus. The University's Maintenance and Operations Division was an ideal choice for study due to the scope of the facilities they maintain and their breadth of experience in facility operations. They are also a strong particip nt in and supporter of Computer Integrated Construction research.

3.2.1. Organizational Structure

The Pennsylvania State University's Maintenance and Operations Division organizational chart is presented in Appendix B. The Maintenance and Operations Division includes staff members for various facilities maintenance trades as well as janitorial and landscaping services, vehicle maintenance, solid waste management, electronic equipment repairs, and recycling services.

3.2.2. Facility Maintenance Trades

The facilities maintenance trades (building, mechanical, and electrical) are primarily responsible for providing operational classroom and research facilities. They are led by ten trade supervisors and are organized into crews and shops consisting of tradepersons responsible for building materials (concrete, masonry, metals, drywall, paint, etc.), systems (plumbing, heating, refrigeration, electric, fire alarms, etc.), and components (pumps, elevators, oil burners, etc.). Their various shops are responsible for such things as 8.5 million square feet of roofs, 10,000 exterior doors, and 250 elevators. With a staff of 272 people, they operate around the clock, 365 days a year.

3.2.3. The Trade Supervisors

The trade supervisors fill a unique position between the Division's management and the tradesmen. They do not directly perform maintenance tasks themselves; instead they manage the crews responsible for carrying out the work assignments. Their main purpose is to provide crews with the information and resources needed to complete the work assignments.

3.3. Scope of the Interviews

All of the trades were represented in the interviews. A listing of the individuals interviewed, their respective trades, and the topics discussed is provided as Table 3.1. The maintenance planning manager, who was also interviewed, is responsible for forecasting maintenance for a variety of key components in several of the trades.

All of the principal trades and materials were discussed. Focus was maintained on the items which the trade supervisors identified as most critical, important, or problematic. Sample interview questions and answers are provided in Appendix C.

3.4. Results of the Interviews

The interviews identified a wide array of information needed to support facility operations. Given the broad scope and overlapping nature of the many information items, UCI Index codes and (building) Level codes

Table 3.1: Interviewees and Subjects Discussed

NAME	TRADE(S)	SUBJECTS DISCUSSED
Mr. Bair	Refrigeration Oil burners	Condensors Chillers Cooling towers Oil burners Boilers Fuel systems
Mr. DeBrasky	Maintenance Planning	Ceilings Chillers Doors, int/ext Electrical components Elevators Flooring Masonry Mechanical systems Plumbing systems Painting, int/ext Pumps Roofs
Mr. Ellenberger	Plumbing	Potable water systems Gas, Steam, Air supply Water softeners Waste water piping Heat exchangers Plumbing fixtures Fire sprinkler piping
Mr. Frazier	Field carpentry	Windows & Doors Interior walls Toilet partitions Door types Door hardware Window types Window hardware Classroom seating
Mr. Hahn	Electrical systems Elevators	Fire alarms Security alarms Electrical distribution Lighting Electronics Elevators

(cont. on next page)

Table 3.1 (cont.)

NAME	TRADES	SUBJECTS DISCUSSED
Mr. Harris	HVAC Systems	Air handling equipment Fan coil units Ductwork & dampers Circulation pumps Heat exchangers VAV boxes
Mr. Kuntz	Interior finishes	Painting Carpet, floor tile Wall coverings Ceiling tiles
Mr. Lightner	HVAC Controls	Components System types
Mr. Martin	Pumps Metals Fire systems	Heat pumps Condensate pumps Chilled water pumps Air compressors Sump pumps Ductwork Metal flashing Gutters & downspouts Sprinkler systems Fire extinguishers
Mr. Powers	Roofing Masonry	Roofing systems Masonry, bricks, etc. Dryvit type sheathing Concrete
Mr. Tepsic	Locks & Hardware Asbestos removal Misc. Maintenance	Door hardware parts Electronic locks Asbestos removal Light fixture ballasts Plumbing fixtures Window blind systems Classroom seating Projection screens Stair treads Window A/C units Pipe coverings

were selected to compile and present the results (See Table 3.2). For each piece of information, corresponding possible information sources were identified (more than one may apply). Each of the codes used to present the results is explained below.

3.4.1. Explanation of UCI Index Codes

The Index code (first column of Table 3.2) refers to the Uniform Construction Index (UCI) [CSI, 1978]. To put the information in a logical order, the UCI division and broadscope titles were used. The UCI system was selected because of its high degree of correlation to the facility trades. For each trade and topic discussed, it was found that there was a corresponding UCI code.

Items are listed in Table 3.2 in increasing order of UCI division from 3 (Concrete) to 16 (Electrical). Site Work, Equipment, and Special Construction (divisions 2, 11, and 13, respectively) were omitted since they did not apply to the study.

Index codes were assigned at the highest possible UCI level. For instance, information about cold water systems (UCI 15401) and hot water systems (UCI 15402) were grouped into the broader section called plumbing systems (UCI 1540-). Dashes were used in the code numbers as "wild cards," indicating that the information generally pertains to all UCI codes beginning with the digits shown.

Table 3.2: Compiled Interview Results

UCI Index Code	Level	Information	Source (see key)
03--- Concrete	Comp	Type (pre-cast, CIP)	A S I
		Curing compound, sealant type	A S I
04--- Masonry	Comp	Type (CMU, stone, glazed)	A S I
		Manufacturer, style no., color no.	A S M
		Unit size	A I
		Sealant type	A S I
		Mortar mix design	AS
		Mortar color (if any)	A S M
05--- Metals	Floor	Framing sizes, dimensions	A I
	Room	Framing details	A D I
	Comp	Color of finish metals	A S M I
06--- Wood & Plastics	Floor	Framing sizes, dimensions	A I
	Room	Framing details	A D I
07--- Thermal & Moist. Protection	Floor	Roof plan	A I
		Size (SF)	A I
		Roof material type	A S I
		Roof condition	I
	Comp	Manufacturer, product no.	A S M
		Color no. (for siding)	A S M
		Roof warranty (Note 1)	S M O
		Flashing, gutter material type	A S I
08--- Doors & Windows	Floor	Locations of doors & windows	A I
	Room	Locations of doors & windows	A I
	Comp	Material (wood, metal, aluminum)	A S I
		Size (dimensions, profile, etc.)	A M D I
		Condition/replacement priority	I
		Manufacturer, model no., color no.	A S M I
		Style (handicap, etc.)	A S D I
		Hardware items (knobs, etc.)	A S D I
		Door orientation (left or right hand)	A S D I
		Door fire rating	A S M I
		Glazing type (thermal, safety, etc.	A S M I
		Lock core or key numbers (Note 2)	S M D

Key to Sources of information:
A = Drawings, S = Specifications, M = Manufacturer literature, D = Shop Drawings, O = Operation and Maintenance Manuals, I = On-site Inspection

Note 1: Information also contained in the actual warranty.

Note 2: Key core numbers, serial number, test reports, etc. may be provided separately.

Note 3: This information is not currently maintained.

(cont. on next page)

Table 3.2 (cont.)

UCI Index Code	Level	Information	Source (see key)
09--- Finishes	Room	Location	A I
		Types (Paint, tile, carpet)	A S I
		Area (SF)	A I
		Condition/replacement priority	I
		Wall fire rating	A S I
	Comp	Manufacturer, color No., model No.	A S M
		Style (semi gloss, flat)	A S I
		Seam direction of carpet (Note 3)	A S D I
10--- Specialties	Floor	Location	A I
	Room	Location	A I
	Comp	Manufacturer, model no., color	A S M
1052- Fire Extinguisher	Comp	Style (water, halon, etc.)	A S M I
		Condition	I
125-- Window Treatment	Comp	Manufacturer, style, color	A S M I
		Dimensions	A M I
127-- Multiple Seating	Comp	Manufacturer, style	A S M I
142-- Elevators	Bldg	Location of cars & mechanical room	A I
		Number of landings	A I
	Floor	Location of cars & mechanical equip.	A I
	Room	Location of components	A I
	Comp	Manufacturer, model no.	A S M I
		Type (hydraulic, cable)	A S M I
		Size (No. of pax)	A S M I
		M & O procedures	O
		Wiring schematics	A M O
		Emergency procedures	M O
		Inspected condition	I
		Warranty (Note 1)	S M O
150-- Materials	Room	Locations	A I
	Comp	Size, capacity	A S M I
1514- Pumps	Comp	Style of pump (centrifugal, etc.)	A S M I
		Manufacturer, model no.	A S M I
1525- Insulation	Comp	Material type	A S I
		Thickness, Rating	A S M I

Key to Sources of information:

A = Drawings, S = Specifications, M = Manufacturer literature, D = Shop Drawings, O = Operation and Maintenance Manuals, I = On-site inspection

Note 1: Information also contained in the actual warranty.

Note 2: Key core numbers, serial number, test reports, etc. may be provided separately.

Note 3: This information is not currently maintained.

(cont. on next page)

Table 3.2 (cont.)

UCI Index Code	Level	Information	Source (see key)
153-- Special Piping Systems	Bldg	System type (gas, air, vacuum, etc.)	AS
		Schematic diagram	A
		Riser diagram	A
		Location of main shutoff	A I
	Floor	Layout diagram	A I
		Valve & component locations	A I
		Access panel location	A I
		Pipe sizing	A I
		Pipe material	A S I
1540- Plumbing Systems	Bldg	Schematic diagram	A
		Riser & vent diagram	A
		Location of main shutoff	A I
	Floor	Layout showing valves, cleanouts	A I
		Access panel location	A I
		Pipe sizing	A I
		Pipe material	A S I
1542- Plumbing Equipment	Comp	Type (HW heater, softener, etc.)	A S I
		Piping diagram	A I
		Manufacturer, model no.	S M
		Operating procedures	O
		Maintenance procedures	O
		Warranty (Note 1)	S M O
1545- Plumbing Fixtures	Comp	Manufacturer, model no.	A S M
		Installation template	M D O
155-- Fire Protection	Bldg	Type (wet, dry, pre-action, etc.)	A S I
		Riser diagram	A
		Schematic diagram	A
		Shutoff valve location	A O I
	Floor	Layout diagram	A I
		Location of components	A I
		Pipe size, material	A I
	Room	Location of heads	A I
	Comp	Sprinkler head temp. rating	A S M

Key to Sources of information:
A = Drawings, S = Specifications, M = Manufacturer literature, D = Shop Drawings, O = Operation and Maintenance Manuals, I = On-site Inspection

Note 1: Information also contained in the actual warranty.
Note 2: Key core numbers, serial number, test reports, etc. may be provided separately.
Note 3: This information is not currently maintained.

(cont. on next page)

Table 3.2 (cont.)

UCI Index Code	Level	Information	Source (see key)
1560- Power & Heat Generation	Floor	Location	A I
	Room	Location	A I
		Style (Steam, Hot water, etc.)	A S M I
		Isolation valve locations	A O I
	Comp	Warranty (Note 1)	S M I
		Operation procedures	O
		Maintenance procedures	O
		Manufacturer, model	S M
		Capacity, size	A S M I
		Schematic diagram	M D O
		Boiler pressure	A S M I
		Relief valve type, rating	A S M I
1565- Refrigeration Equipment	Floor	Location	A I
	Room	Location	A I
		Isolation valve location	A S M I
	Comp	Manufacturer, model	A S M I
		Warranty (Note 1)	S M
		Operation procedures	O
		Maintenance procedures	O
		Capacity, size	A S M I
		Schematic diagram	M D O
		Serial number (Note 2)	O I
157-- Liquid Heat Transfer	Bldg	System type (hot water, steam, etc.)	A I
		Schematic diagram	A
		Riser diagram	A
		Location of main shutoff	A I
	Floor	Layout diagram	A I
		Access panel location	A I
		Pipe sizing	A I
	Comp	Pipe material	A S M I
		Equipment manufacturer, model	S M
		Equipment schematics	M O I

Key to Sources of information:
A = Drawings, S = Specifications, M = Manufacturer literature, D = Shop Drawings, O = Operation and Maintenance Manuals, I = On-site Inspection

Note 1: Information also contained in the actual warranty.

Note 2: Key core numbers, serial number, test reports, etc. may be provided separately.

Note 3: This information is not currently maintained.

(cont. on next page)

Table 3.2 (cont.)

UCI Index Code	Level	Information	Source (see key)
158-- Air Distribution	Bldg	Riser diagram	A
		Sequence of operations	A S O
		Test & Balance report (Note 2)	O I
	Floor	Location of components	A I
		Layout diagram, sizing	A I
		Material types	A S M
	Comp	Equip. manufacturer, model	S M
		Equip. vendor	M
		Equipment schematic	M O
		Fire damper rating	A S M
159-- Controls & Instrumentation	Bldg	System type (air, electronic)	A S I
		System schematic	A O
		Sequence of operations	A S O
		Zones (heating, cooling)	A O
		Test & Balance report (Note 2)	O I
		Operation & Maintenance procedures	O
	Floor	Location of main components	A I
	Room	Location of components	A I
	Comp	Manufacturer, model no.	A S M I
		Schematics	M
1615- Motors	Comp	Manufacturer, model no.	A S M I
		Size, volts, amps, hp	S M I
		Maintenance procedures	O
		Condition	I
1616- Panelboards	Comp	Panel size	A M I
		Panel capacity (amps)	A M I
		Breaker types	A S M I
		No. spare breakers	A S I
		Condition	I

Key to Sources of information:
A = Drawings, S = Specifications, M = Manufacturer literature, D = Shop Drawings, O = Operation and Maintenance Manuals, I = On-site Inspection

Note 1: Information also contained in the actual warranty.

Note 2: Key core numbers, serial number, test reports, etc. may be provided separately.

Note 3: This information is not currently maintained.

(cont. on next page)

Table 3.2 (cont.)

UCI Index Code	Level	Information	Source (see key)
164-- Service & Distribution	Bldg	Schematic (single line) diagram	A
		Main disconnect/breaker location	A I
		Conduit, conductor size	A S I
	Floor	Layout, wiring	A S I
	Room	Layout, wiring	A S I
	Comp	Conductor material	A S I
		Panel schedule	A I
165-- Lighting	Floor	Layout, wiring diagram	A
	Room	Layout	A
	Comp	Fixture type (fluorescent, HP, etc.)	A S M I
		Manufacturer, model	A S M I
		Condition of fixtures & wiring	I
167-- Communications	Bldg	Location of main panel	A I
		System schematic diagram	A O
		Zones (i.e. fire detection, security)	A O
		Operating procedures	O
	Floor	Location of components	A I
		Wiring diagram	A
	Room	Location of components	A I
	Comp	Manufacturer, model no.	A S M I
		Maintenance procedures	O

Key to Sources of information:
A = Drawings, S = Specifications, M = Manufacturer literature, D = Shop Drawings, O = Operation and Maintenance Manuals, I = On-site Inspection

Note 1: Information also contained in the actual warranty.

Note 2: Key core numbers, serial number, test reports, etc. may be provided separately.

Note 3: This information is not currently maintained.

3.4.2. Explanation of Level Codes

The Level code refers to the scope of the information. The four Level codes, and their corresponding scopes, are:

Code:	Information pertains to:
BLDG	building as a whole
FLOOR	a floor within the building
ROOM	a room within a floor
COMP	an individual component

The basis for selecting these four levels was that the types of information desired by the trade supervisors differed for each level. When considering the building plumbing system (Index 1540-) as a whole, for example, schematic diagrams, the location of the main shutoff valve, and identity of the system type (gas, steam, air, water, etc.) are most useful. At the Floor level, a piping layout diagram, showing access panel locations and pipe sizes and materials, is preferred.

3.4.3. Explanation of Information Sources

The Source codes in Table 3.2 identify where each item of information **might** be found. Some, none, or all of the sources identified could contain the information, due to the lack of an industry standard for organizing building information.

The code letters used and items they represent are:

Code	Source represented
A	Facility drawings
S	Specifications
M	Manufacturer literature
D	Shop drawings
O	Operation and maintenance manuals
I	On-site inspection

Other sources cited less frequently were: warranties, test reports, and serial numbers. These items are identified by the appropriate footnotes which accompany the information item.

3.5. Observations Based on Interviews

Based upon the interviews, several observations were made.

3.5.1. Time Critical Information Requirements

The priority for accessing the many information items varied. The most time critical information requirements identified during the interviews included:

1. Knowing the location of isolation valves for piping systems and main disconnects for the electrical system.

2. Knowing the location of a building's elevator mechanical room (people frequently get trapped inside the elevators).

3. Knowing the composition of a roof and whether or not it is covered by a warranty.

4. Knowing the location and the operation and maintenance procedures for major mechanical systems.

3.5.2. Overlapping Lines of Responsibility

There was a slight overlap noted in the information provided by several supervisors due to overlapping lines of responsibility. A light fixture provides a good example. The Electrical Trades Supervisor is responsible for the light fixture and associated wiring; the Miscellaneous Maintenance Trades Supervisor is responsible for the bulbs and ballast; and the Maintenance Planning Manager is responsible for documenting the overall condition of lighting systems. Other areas which exhibited a similar overlap include the plumbing system, sprinkler system, and classroom seating. This overlap was helpful in that it gave several viewpoints about the same item.

3.5.3. Reliance on Experience and Inspection

The trade supervisors did not always rely upon documents to obtain information about facilities. Frequently, the trade supervisors cited personal knowledge and experience as the source for their information. In this case, the questions were rephrased to ask where someone who is **not** knowledgeable about the facility would locate the information.

Similarly, inspecting the job site in person was cited by many as an information source. In the absence of other information sources, this was often the best method known for obtaining the needed information. In these cases, on-site inspection was recorded as a source which combines **with** other sources the interviewee said would be helpful.

3.6. Consolidation of the Information Needs

Based on the specific information collected in the interviews for each facility trade (the third column in Table 3.2), it was concluded that the facility operator's information needs could be generalized into the categories shown in Figure 3.1. The general information categories are essentially a consolidation of specific information items from one or more of the trades. Nine categories are defined. They are:

Geometric: The Geometric category refers to all of the spatial representations of the building, typically found in the facility drawings. Geometric information includes locations of components and

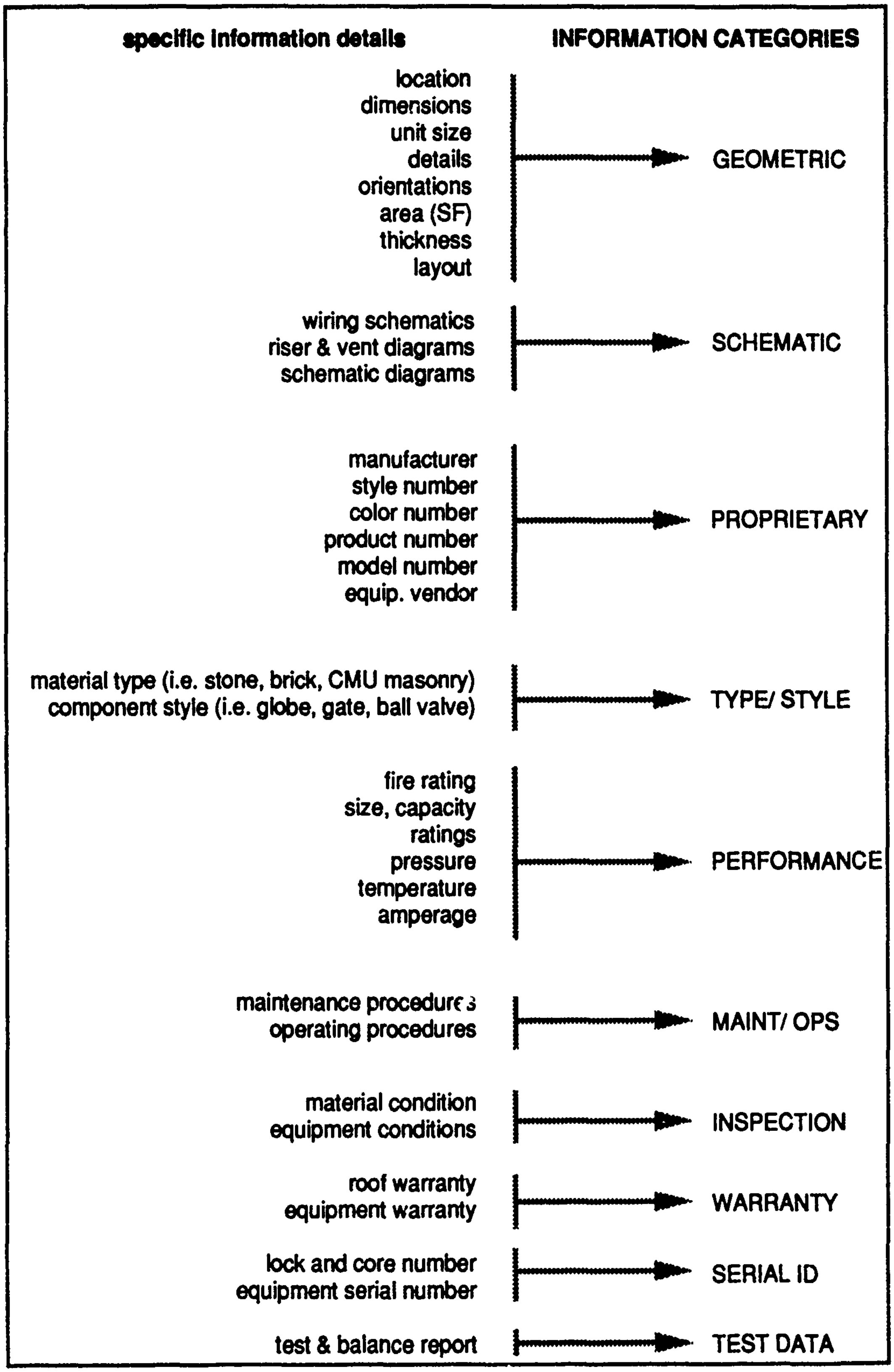


Figure 3.1: Consolidation of Information into Categories

materials; component orientation and system layout; and all dimensions, sizes, and details.

Schematic: The Schematic category refers to diagrammatic representations of systems, for example, electrical single line diagrams. Also included are riser diagrams, control system diagrams, and detailed component wiring diagrams.

Proprietary: This category describes any information related to the maker or vendor of a material or component. It includes information such as the manufacturer's name, the model number, and the manufacturer's color number.

Type/ Style: The Type/ Style of an item identifies a specific attribute from many. For example, types/ styles of masonry could refer to masonry unit, stone, brick, etc. This information is usually found on the drawings and in the specifications.

Performance: Performance refers to quantitative data, typically describing plumbing, mechanical, and electrical equipment. Examples include capacities, sizes, rates, temperatures, pressures, voltages, and amperages.

Maint/ Ops: Short for maintenance and operations information, this category includes system start-up, operation, maintenance, troubleshooting, and emergency procedures. It also includes replacement parts information.

Inspection: Inspection refers to information obtained from periodic inspections, typically describing a component's conditions and priority for replacement.

Warranty: This item refers to the expiration date and the provider of warranties, typically for expensive or critical components and roofs.

Serial ID: This item refers to a unique number describing a component. It is used for major pieces of equipment and also for key numbers to door locks.

Test Data: This category refers to the results of performance tests, for example, the HVAC system test & balance report.

3.7. Requirements for Organizing the Information

As shown in this chapter, the facility operator has a need for a wide array of information items about buildings. The types of information needed were shown to vary for the many materials, components, and systems managed by each trade. Information needs also varied with the various levels within the building (i.e. building, floor, room, and component). Accordingly, UCI Index codes were used to differentiate between each of the materials, components, and systems, and Level codes were used to differentiate between the various levels of the building. Finally, it was shown that the many types and sources of information could be grouped into just nine general categories.

Existing product models, discussed in Chapter 2, provide a basis for the development of a framework to specifically address the information needs of the facility operator. In particular, the RATAS Model and Khayyal's Product Model Architecture offer a logical structure for organizing the operator's information by decomposing the building hierarchically (similar to the Level code) and providing the ability to group objects into "classes" or "disciplines" (similar to the Index code). Khayyal's coding structure also defines an ample number of categories to classify the operator's information (i.e. building level, UCI, SfB, etc). All of the models considered, however, tended to be more broadly defined or sophisticated than needed to accommodate the relatively simple information needs of the facility operator.

3.8. Summary

This chapter has identified the information needs of the facility operator. These needs were defined by interviewing members of a large facility owner's maintenance and operations staff, summarizing the information collected on a system by system basis, and then consolidating the specific items into nine categories: geometric, schematic, proprietary, type/ style, performance, maint/ ops, inspection, warranty, serial ID, and test data. Requirements for organizing the operator's information are then discussed.

Chapter 4

THE FACILITY OPERATOR'S INFORMATION FRAMEWORK (FOIF)

4.1. Overview

This chapter defines the Facility Operator's Information Framework (FOIF). The FOIF is a framework used by the operator to organize and access information about the building. Criteria for the framework are detailed first. Subsequently, an overview of the FOIF is provided and its coding structure is explained. Finally, the use of each code is described.

4.2. Criteria Used for Developing the FOIF

Several criteria were used to develop the FOIF based upon the research results presented in Chapter 3 and the objectives of the study:

1. The FOIF must be able to provide the operator "views" of the building for each major facility trade. For example, electricians should be able to "filter out" unneeded information related to other trades (i.e. plumbing, mechanical, architectural, and structural

systems) leaving just the electrical system, materials, and components displayed (i.e. the "E" drawings). This filtering provides the operator with only the essential information items identified in Chapter 3 for a given system.

2. The FOIF must distinguish between several levels of detail within the building. For example, the FOIF must organize information about the building as a whole, as well as information about individual components. Several levels of detail should be provided.

3. The FOIF must be simple, logical, and adaptable. Only the minimum number of codes needed to identify building components spatially and functionally should be used. Codes should be defined in commonly accepted terms and should be adaptable to future changes in the AEC industry.

4. The FOIF should be defined independently of the information's format. Paper documents, electronic media, or combinations of the two should be accessible regardless of their format.

4.3. Overview of the FOIF

The FOIF meets the criteria established through the use of a simple coding structure. The coding structure consists of four address codes and one information code (see Figure 4.1). Address codes (System, Level, Vantage, and Index) describe where, in the building, something is located and identify the item functionally. The Information code identifies the information categories related to the item and is used to obtain information about the item.

Operation of the FOIF can be better visualized through an analogy: as a database which is viewed through the window of a camera. In order to get information out of the database the camera must first be pointed at the item in question (using the Vantage code). It can then be zoomed in and out to look at the building as a whole or just a single component (with the Level code). Filters (System and Index codes) can be used over the lens so that it sees only certain items (i.e. just the electrical system and its components). Once the appropriate view is obtained, the Information code can be used to select information from the database.

4.4. The FOIF Coding Structure

The five codes comprising the FOIF's coding structure are explained below.

4.4.1. Building Systems ("System")

Five building systems are used in the FOIF: architectural, structural, plumbing, mechanical, and electrical. Each system is defined as a consolidation of UCI divisions. For instance, the electrical system is defined

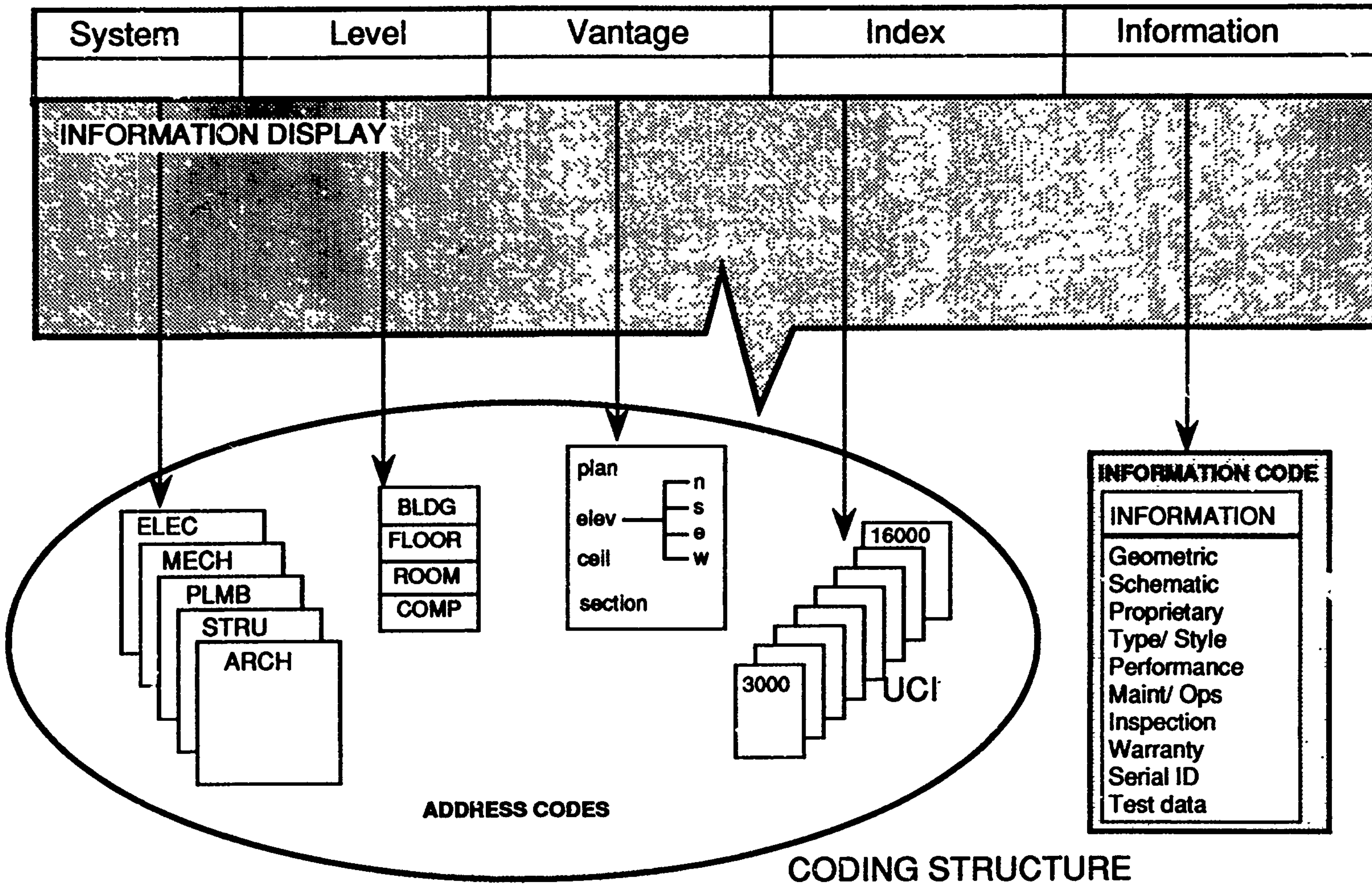


Figure 4.1: The Facility Operator's Information Framework (FOIF)

as all items covered under division 16 of UCI (The UCI system is explained in greater detail in Chapter 2.).

A listing of the five systems, their codes, and their respective UCI divisions is as follows:

System (CODE)	UCI Divisions
Architectural (ARCH)	3 - 10, 12, and 14
Structural (STRU)	3 - 6
Plumbing (PLMB)	15: sections 15100 - 15500
Mechanical (MECH)	15: sections 15100, 15200, and 15600 - 15900
Electrical (ELEC)	16

Note that several systems overlap UCI divisions. For instance, divisions 3 through 6 are included in both architectural and structural systems since concrete, masonry, metals, woods, and plastics (divisions 3 through 6) may be used for either purpose. Divisions 2 (Sitework), 11 (Equipment), and 13 (Special Construction) are omitted since they fall outside the scope of the study. Another area of overlap is with basic materials like conduit, valves, and pipe. Here the idea of connectivity is employed when assigning the material to a particular system. For instance, valves and piping (15100) comprising the plumbing system would be assigned to the plumbing system. Similar valves and pipes connected to the air conditioning system would be assigned to the mechanical system.

The consolidation outlined above is intended to be generic. When organizing information for a particular building, the consolidation scheme could be adjusted easily to accommodate user preference. For example, specific systems such as HVAC Controls (15900), Refrigeration (15650), or Lighting (16500) could be defined as unique systems or subsystems of those defined.

4.4.2. Building Levels ("Level')

Using the Building Level codes proposed by Khayyal [1990] as a baseline, a simplified set of building levels was defined. The levels defined in the FOIF are: Building, Floor, Room, and Component. Figure 4.2 shows the structure of these four levels. The Level "BLDG" refers to the building as a whole. Floors and Rooms are abbreviated as FL and RM, respectively, and use the floor number and room number as part of the code (i.e. FL1, FL2, RM209, RM315, etc.). Basement floors have a "B" prefix (i.e. B1, B2, B3, ...) and the roof level is "FLROOF." Hallways and stairways can be assigned regular room numbers or follow a unique numbering system preceded by an "H" or "S," for instance. The component level ("COMP") is shown as a bubble in Figure 4.2 to illustrate the idea that components need not be the lowest level in the FOIF. Components can be collections of other components. For instance, a door is considered to be a component while the knob, hinges, and lockset attached are also considered to be components. These Levels are generic in definition and can also be tailored to suit individual building or user requirements.

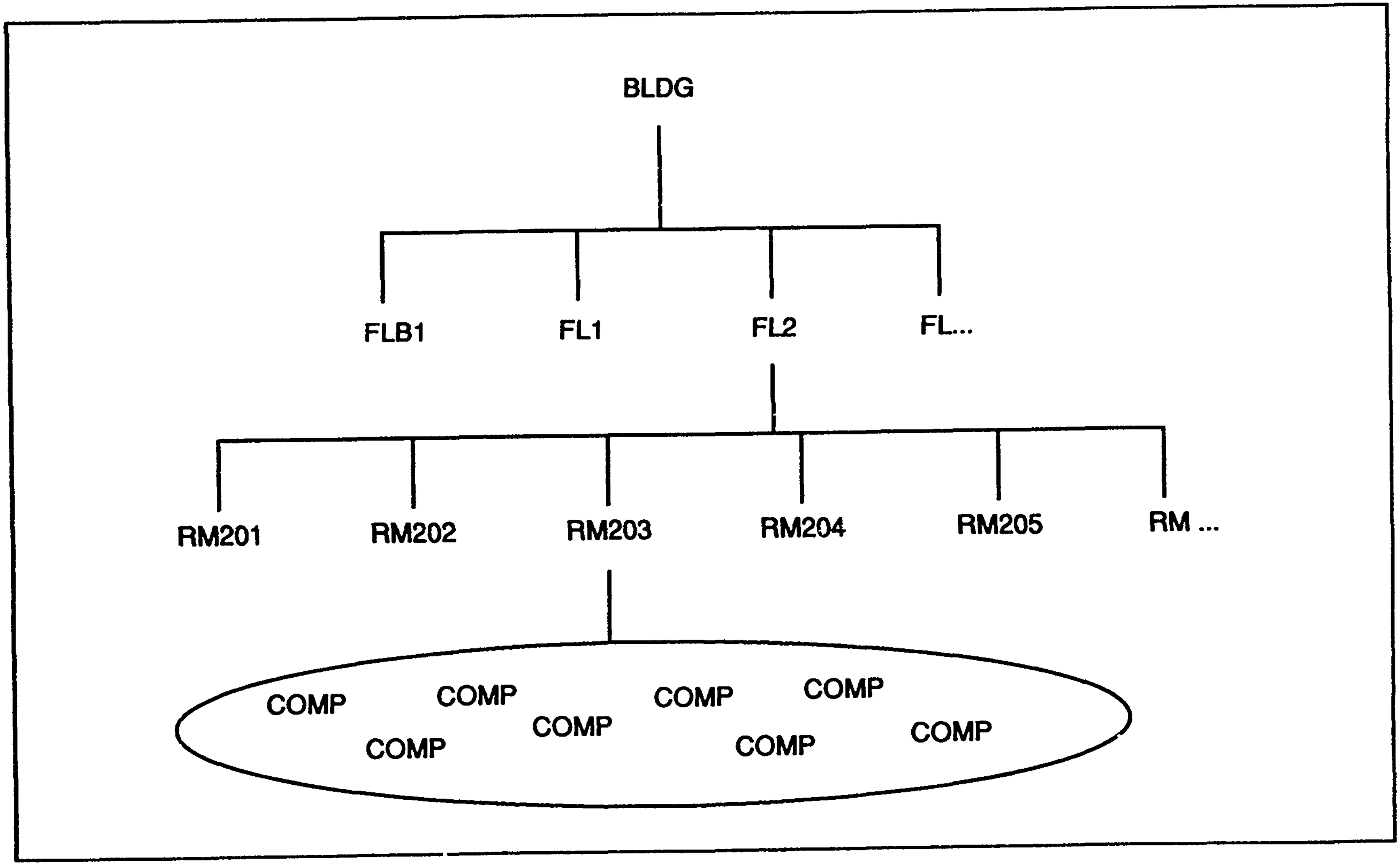


Figure 4.2: Building Level Structure

4.4.3. Geometric Vantage Point ("Vantage")

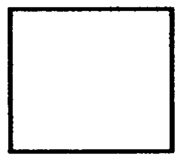
The geometric vantage points are used to select a representation of the building geometry. The FOIF defines Vantage codes for both two- and three-dimensional graphics as shown in Figure 4.3. In terms of conventional two-dimensional drawings, common vantages would be: floor plans, typical wall sections, and reflected ceiling plans. Cross-sectional drawings of each surface are also defined. To support three-dimensional representations of the building geometry the vantages are: down; north, south, east, and west; and up. Cross sections of each surface would also be available.

The Vantage code would not be used at the component level unless more than one representation of the component was available. For instance, some pieces of mechanical equipment may have elevation drawings showing the equipment from several different angles. In this case, the Vantage code would be used to differentiate between the different angles.

4.4.4. UCI Code ("Index")

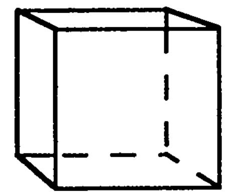
The Uniform Construction Index (UCI) is used as the final category for organizing items within a building. Each material, component, and system is described in the UCI. When coding and storing items, the proper five-digit UCI code is assigned.

TWO-DIMENSIONAL VANTAGE POINTS



VANTAGE POINT	CODE
PLAN VIEW	PLAN
ELEVATION-NORTH	EL-N
-SOUTH	EL-S
-EAST	EL-E
-WEST	EL-W
CEILING	CEIL
SECTION	S

THREE-DIMENSIONAL VANTAGE POINTS



VANTAGE POINT	CODE
DOWN	DOWN
NORTH	NORTH
SOUTH	SOUTH
EAST	EAST
WEST	WEST
UP	UP
SECTION	S

Figure 4.3: Geometric Vantage Points, Two- and Three-Dimensional

The Index is the greatest level of detail for describing items functionally. Consequently, this category differentiates between the items which have the same code structure for System, Level, and Vantage. It should be noted that some items cannot be differentiated. An example would be the hardware associated with a particular door. Hinges, strike plates, and knobs are all identified by the same UCI narrowscope title (08710) and can thus not be differentiated in the coding structure.

Because of the way in which Systems are defined (i.e. as consolidations of many Index codes) all items within a system are selected. For instance, a structural plan would show all items described by codes 03000 through 06000. It is only when a particular item is to be singled out, for instance steel framing members, that specific indices (05000) are needed. Several could be selected for display.

There are several advantages to using the UCI as a basis for the FOIF:

1. It is common. The UCI is widely recognized as the standard in the United States construction industry.
2. It is comprehensive. All items in a building can be described by a UCI Code.
3. It is adaptable. The UCI is constantly changing to accommodate new technologies.

4.4.5. The Information Code ("Information")

Chapter 3 identified nine general categories to describe information about buildings most useful to the facility operator. These items are used in the FOIF to access the appropriate source(s) for the information. For instance, most "Geometric" information code queries would access the facility drawings; "Type/ Style" queries might access charts and schedules in the drawings or specifications. A full listing of the Information codes is provided in Figure 4.1. The types of information accessed by each code were listed in Figure 3.1.

4.5. Using the FOIF

The principle use of the FOIF is to give the operator access to facility information by providing a logical system for its organization. Information retrieval procedures are discussed first by considering each code individually. Subsequently, information storage is presented in general terms. Retrieval and storage procedures are both discussed in terms of a generic computer environment, but are described independently of the information's format.

4.5.1. Retrieving Information

The basic procedure for retrieving information with the FOIF begins by specifying the address codes (System, Level, Vantage, and Index) and then by selecting the information code representing the type of data needed.

4.5.1.1. Using the System Code

Typically the first code selected would be the System code. System codes define an appropriate "view" of the building for each user. For instance, a plumbing tradesman's view would be defined by the System code "PLMB." Selecting the "PLMB" System code can be thought of as starting with a complete set of the facility's drawings and then turning to the plumbing ("P") drawings.

Normally only one System code would be selected at a time. Selecting more than one system at a time should result in the superimposition of the systems selected. If no System code is selected the default would be the architectural system. Other default settings could be defined by the user.

4.5.1.2. Using the Level Code

Inquiries would begin at the Building level. Floors and rooms would be selected by the user pictorially (i.e. by using a "point and click" or similar technique) or by selecting the appropriate Level code or Floor number and Room number from a list of available choices. For instance, from a "BLDG" level display the user could click on the third floor for a third floor plan or simply select the code "RM309" to display a floor plan of Room 309.

Selection of components would be made pictorially, as described above, or by using the Index code as explained in Section 4.5.1.4.

4.5.1.3. Using the Vantage Code

The Vantage code selects a representation of geometric data (i.e. drawings). Unless otherwise specified, the Vantage is a plan view (two-dimensional) or an elevation view (three-dimensional). With three dimensional graphics, vantage could be controlled by a "joy stick" or similar input device which allows for panning and movement in four directions. Cross-sectional representations are accessed by first specifying the desired vantage (i.e. floor plan, wall elevation, or ceiling) and then selecting "S" from the Vantage menu.

4.5.1.4. Using the Index Code

Within a view which has been defined by the other three address codes of the FOIF coding structure (i.e. PLMB, RM103, PLAN), one or more items can be displayed, with each represented by an Index code. For example, given the above code, a domestic water heater (15424), some pipes (15063), and a floor drain (15421) might be displayed on a floor plan of Room 103. Selection of a specific component would then be made by clicking on the desired item.

4.5.1.5. Using the Information Code

Given a full address code, information about the item would be retrieved by selecting from available information codes. Unless otherwise selected, "Geometric" information would be displayed.

4.5.2. Storing Information

The physical storage of information could be accomplished electronically. Information would be input by scanning existing documents or transferring electronically generated/ stored information into a frame. This frame would be assigned a retrieval code based on the proposed FOIF coding structure and accessed by a similarly based query language.

Voluminous paper documents (i.e. operations and maintenance manuals) or other documents not suited for electronic storage might be arranged in a conventional filing system. Queries for such documents would provide the shelf address, for example "See shelf B6 in reference library."

4.6. Summary

This chapter defined the FOIF, a useable framework for organizing information so that it can be easily retrieved by the facility operator. Organization is accomplished by a simple coding structure consisting of address codes, which locate and describe an item, and an information code, which provides information about the item. In Chapter 5, the framework is tested with a case study.

Chapter 5

CASE STUDY

5.1. Overview

A case study was used to test the ability of the Facility Operator's Information Framework (FOIF) to identify locations of problems within a building. Actual work assignments at a representative building were used. The case study results are listed and discussed. It is shown that, in general, the FOIF coding structure can be used to effectively locate items within a building.

5.2. Agricultural Science and Industries Building

The building selected for the case study was the Agricultural Science and Industries Building, which is located at the University Park Campus of The Pennsylvania State University. This recently constructed building is a five-story, 150,000 square foot office, laboratory, and classroom facility. It features standard architectural, structural, plumbing, mechanical, and electrical systems. It also features several specialized systems such as distilled water, compressed air, and vacuum systems. The facility, although only in operation for less than a year, provided an ample variety of work assignments for study.

5.3. Description of the Work Assignments

Work assignments are used by The Pennsylvania State University's Maintenance and Operations Division to define requests for repairs or maintenance. For the case study, a printout listing completed work assignments for the Agricultural Science and Industries Building was obtained. The majority of the work assignments on the listing were requests to have keys made; to locate and repair leaks; to have modifications made; to install furnishings and equipment; or to repair computer equipment.

The available list was reduced slightly before selecting work assignments for the case study. Computer repairs were excluded as beyond the scope of this study. Duplications of similar assignments were eliminated, leaving only the first occurrence of each type of call. All assignments involving duplication of keys were dropped in favor of one assignment to repair a faulty lockset (which requires locating the same object). Duplicate assignments involving leaks were only partially eliminated. Though repetitious in description, many "repair leak" assignments involved different systems and were selected on this basis rather than by the description of work alone. In all, approximately sixty assignments had to be considered in order to obtain fifteen which represented a variety of problems encompassing each major trade.

5.4. Case Study Illustration and Results

The purpose of the case study was to test the ability of the FOIF to describe the location of building components both spatially and functionally and, thus, provide the user with information about the component. For each of the fifteen work assignments, the item described was located using the facility documents (primarily drawings). Typically, several drawings were needed. Subsequently, the FOIF was used to locate the same item. For instance, if a floor plan of a particular room was needed for the work assignment, the FOIF coding structure which described a floor plan of the room was generated. In cases where a FOIF code was not required to define the drawing, the code is listed "NR" (not required).

One small obstacle encountered was that the room numbering scheme used for work assignments differed from that used on the drawings. Pursuant to facility turnover, the University renumbered all of the rooms to conform with a campus-wide numbering convention. For clarity in presenting the sample cases, the original numbering scheme used on the drawings was adopted for the case study. Room numbers listed on the work assignments were translated back to the old numbering scheme.

5.4.1. Illustration of Cases 4 and 13

To illustrate the case study process, two representative cases are explained:

Case 4 (Work Assignment #29 74184) is an assignment to repair a light fixture in Room 1211. The first drawing needed to locate the problem was a lighting plan of Room 1211 (see Figure 5.1). To obtain this drawing with the FOIF, the System code "ELEC" (electrical system), Level code "RM1211" (Room 1211), and Index code "16500" (lighting system) would be selected. The Vantage and Information codes default to "PLAN" and "Geometric," respectively. Translated into words, the coding structure would read "a lighting plan of Room 1211." The next information needed was a schedule of light fixtures used in Room 1211 (see Figure 5.2). To obtain the same schedule with the FOIF, the Information code would have to be changed to "Type/ Style." The final schedule needed, as shown in Figure 5.3, describes the various types of light fixtures. It would be accessed by the FOIF by changing the Level code to "COMP." Translating this final code into words, it reads "electrical system (System = ELEC) lighting (Index = 16500) components (Level = COMP) found in Room 1211 (from previous screen).

Case 13 (Work Assignment #27 80066) as to repair a broken soap dispenser in the third floor women's restroom. The first drawing needed to locate the problem was an architectural floor plan of the third floor. This drawing indicates that there is only one women's restroom on the third floor and also indicates where on the floor it is located. Next, an enlarged view of the restroom is needed to locate the soap dispenser within the restroom. Figure 5.4 shows the

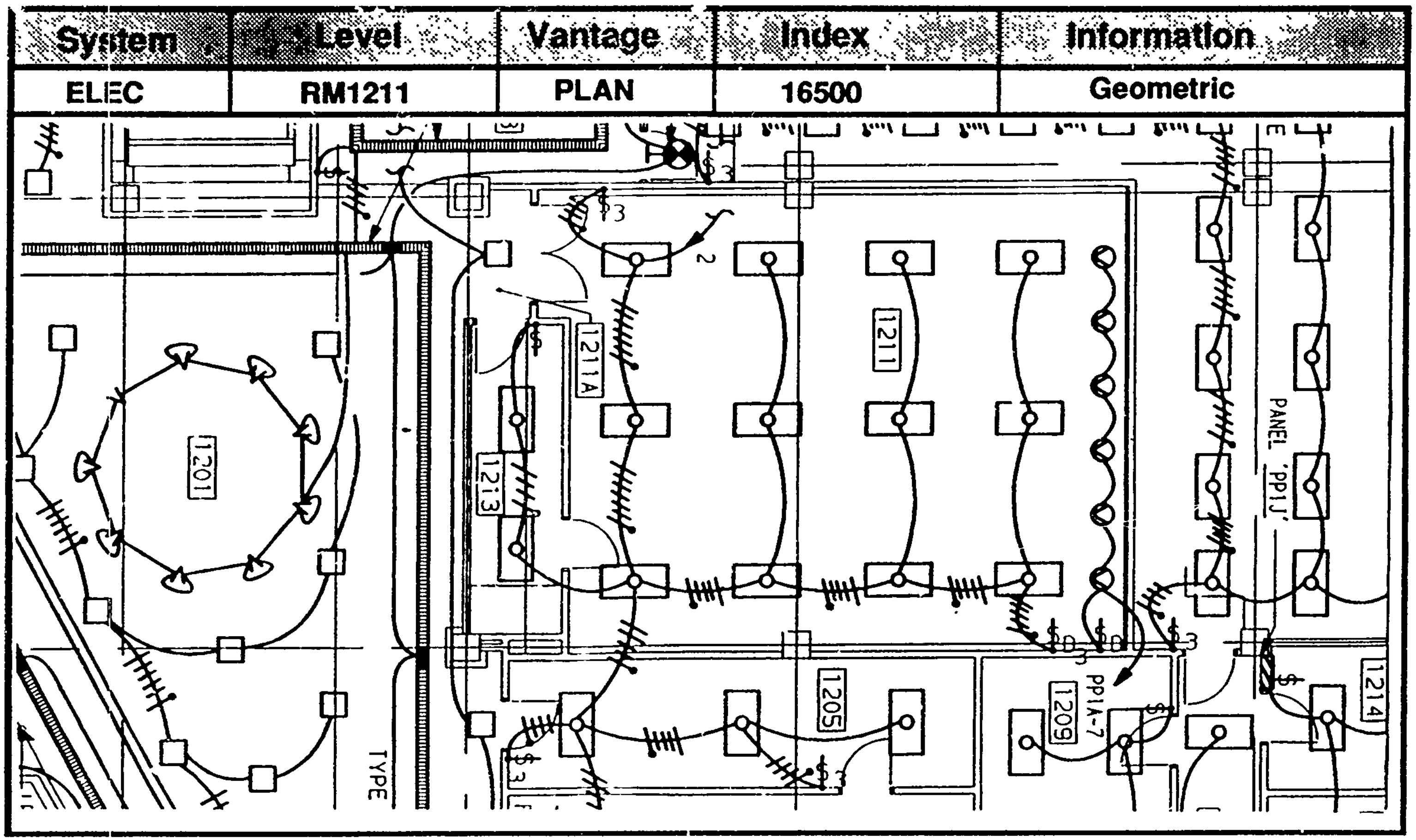


Figure 5.1: Example of Frame for Case 4: Room 1211 Lighting Plan

System	Level	Vantage	Index	Information
ELEC	RM1211	PLAN	16500	Type/Style

ROOM FIXTURE SCHEDULE				
ROOM	FIXTURE	MOUNTING	HEIGHT	REMARKS
1202	AL	RECESSED		
1202A	D	PENDANT	9'-0"	
1203	AL	RECESSED		
1204	H	RECESSED		
1205	C	RECESSED		
1206	G,P	RECESSED		TYPE 'G' W/ DIMMING BALLASTS
1207	C	RECESSED		
1208	A	RECESSED		
1209	C	RECESSED		
1210	A	RECESSED		
1211	G,P	RECESSED		TYPE 'G' W/ DIMMING BALLASTS
1211A	AA	RECESSED		SEE NOTE 7
1212	A	RECESSED		
1213	C	RECESSED		
1214	A	RECESSED		

Figure 5.2: Example of Frame for Case 4: Room Fixture Schedule

System	Level	Vantage	Index	Information
ELEC	COMP	NR	16500	Type/Style

System Level Vantage Index Information
System Level Vantage Index Information

LIGHTING FIXTURE SCHEDULE

LAMP TYPES -FL, FLUORESCENT; IN, INCANDESCENT; MV, MERCURY VAPOR; MH, METAL HALIDE;
HP, HIGH PRESSURE SODIUM; LP, LOW PRESSURE SODIUM; Q, QUARTZ
ENVIRONMENT-IN, INDOOR; DL, DAMP LOCATION; WL, WET LOCATION; HZ, HAZARDOUS; CR, CORROSIVE
MOUNTING -R, RECESSED; S, SURFACE; P, PENDANT; W, WALL; PL, POLE

TYPE	MANUFACTURER	CAT.NO.	DESCRIPTION	LAMPS			ENV/R	MOUNTING		VOLTS	REMARKS
				NO.	WATTS	TYPE		TYPE	HEIGHT		
G	COLUMBIA	P4-242G-43263-1-277V	PARABOLIC LAY-IN	2	34	FL	IN	R	—	277	12 CELL LOUVER(h)
H	COLUMBIA	P4-243G-43363-1-277V	PARABOLIC LAY-IN	3	34	FL	IN	R	—	277	18 CELL LOUVER(c) (h)
J	EXIDE	100-101 WITH 100-552	EXIT LIGHT	2	15	IN	IN	W	7'-4"	277	BACKWALL MTD ARROWS AS INDICATED
K	EXIDE	100-105 WITH 100-552	EXIT LIGHT	2	15	IN	IN	W	7'-4"	277	END MTD-DOUBLE FACE ARROWS AS INDICATED
L	EXIDE	100-101 WITH 100-552	EXIT LIGHT	2	15	IN	IN	W	7'-4"	277	END MTD-SINGLE FACE ARROWS AS INDICATED
M	COLUMBIA	SPS4G-52-244-277V	LAY-IN	4	34	FL	IN	R	—	277	PRISMATIC LENS
N	PRESCOLITE	93075	6" SQUARE DOWNLIGHT	1	150	IN	IN	R	—	120	PAR-38 FLOOD
P	PRESCOLITE	93065	6" SQUARE WALL WASHER	1	150	IN	IN	R	—	120	R-40 FLOOD

Figure 5.3: Example of Frame for Case 4: Lighting Fixture Schedule

System	Level	Vantage	Index	Information
ARCH	RM3132	PLAN	NR	Geometric

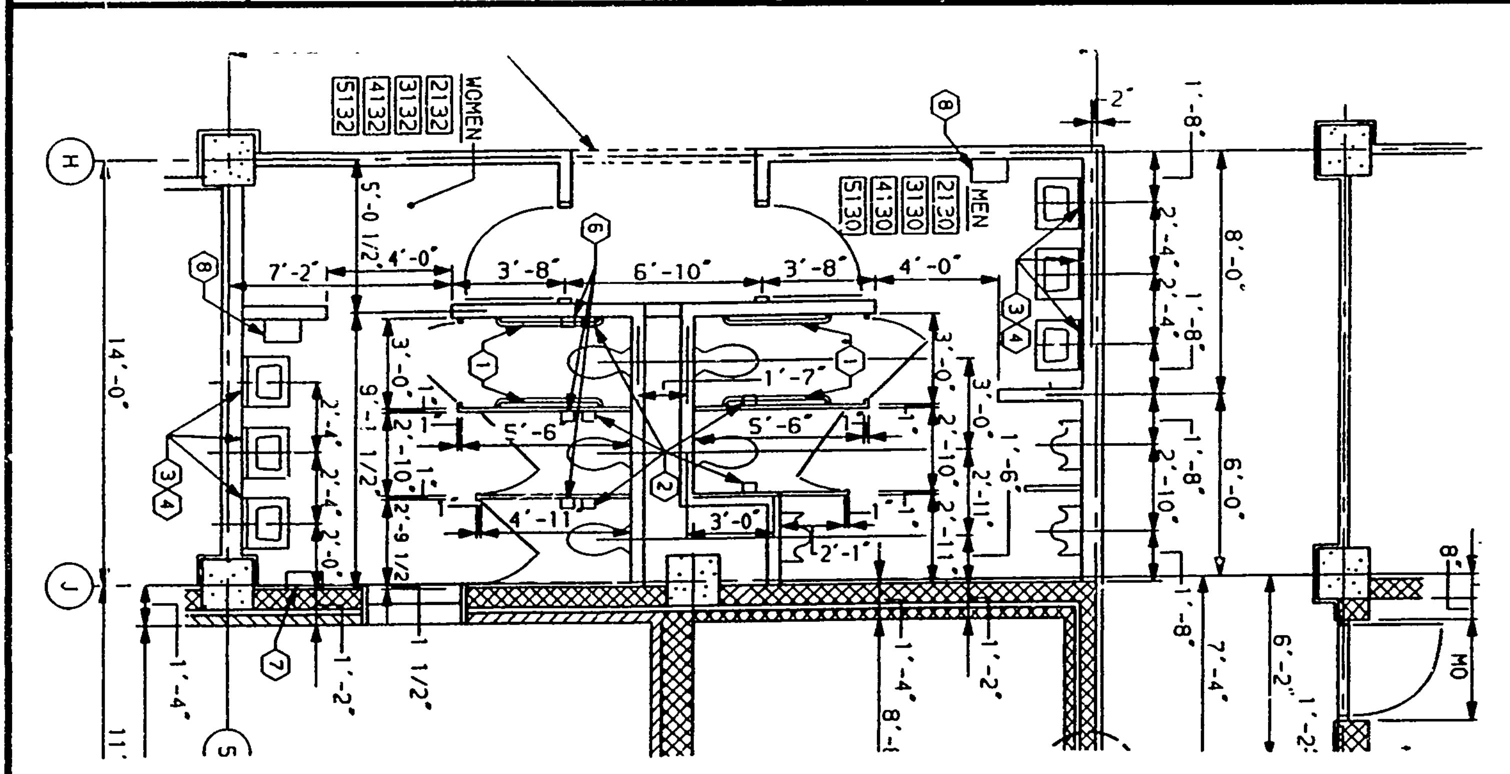


Figure 5.4: Example of Frame for Case 13: Room 3132 Architectural Plan

enlarged architectural plan of typical men's and women's restrooms on floors two through five. The appropriate FOIF coding structure is: the architectural (System = ARCH) floor plan (Vantage = PLAN) of Room 3132 (Level = RM3132). The FOIF Index code is not needed since the System selected ("ARCH") includes all architectural items (including soap dispensers). Though the soap dispensers are labelled on the floor plan drawing, an elevation drawing (Figure 5.5) is added for clarity to show the wall on which the soap dispenser is mounted. The coding structure is similar to the last screen; it is described by changing the Vantage code to "EL-N" or north elevation. Figure 5.6 is the schedule which lists the soap dispenser and is described by changing the FOIF Index code to 10800 (toilet and bath accessories) and selecting the "Type/ Style" Information code.

5.4.2. Tabular Listing of Results

Table 5.1 lists all fifteen work assignments considered in the case study. In the first column, the drawings used to locate the problem are identified by sheet number and drawing title. For each one, the appropriate FOIF coding structure which would access the drawing is shown in the center columns of the table. The last column in the table states whether the FOIF code accurately describes each drawing and lists exceptions.

In cases where the exact subject of the problem was indeterminate, all related drawings were listed. For instance, all drawings showing piping in the vicinity of a water leak are listed. In the case of the fire alarm trouble

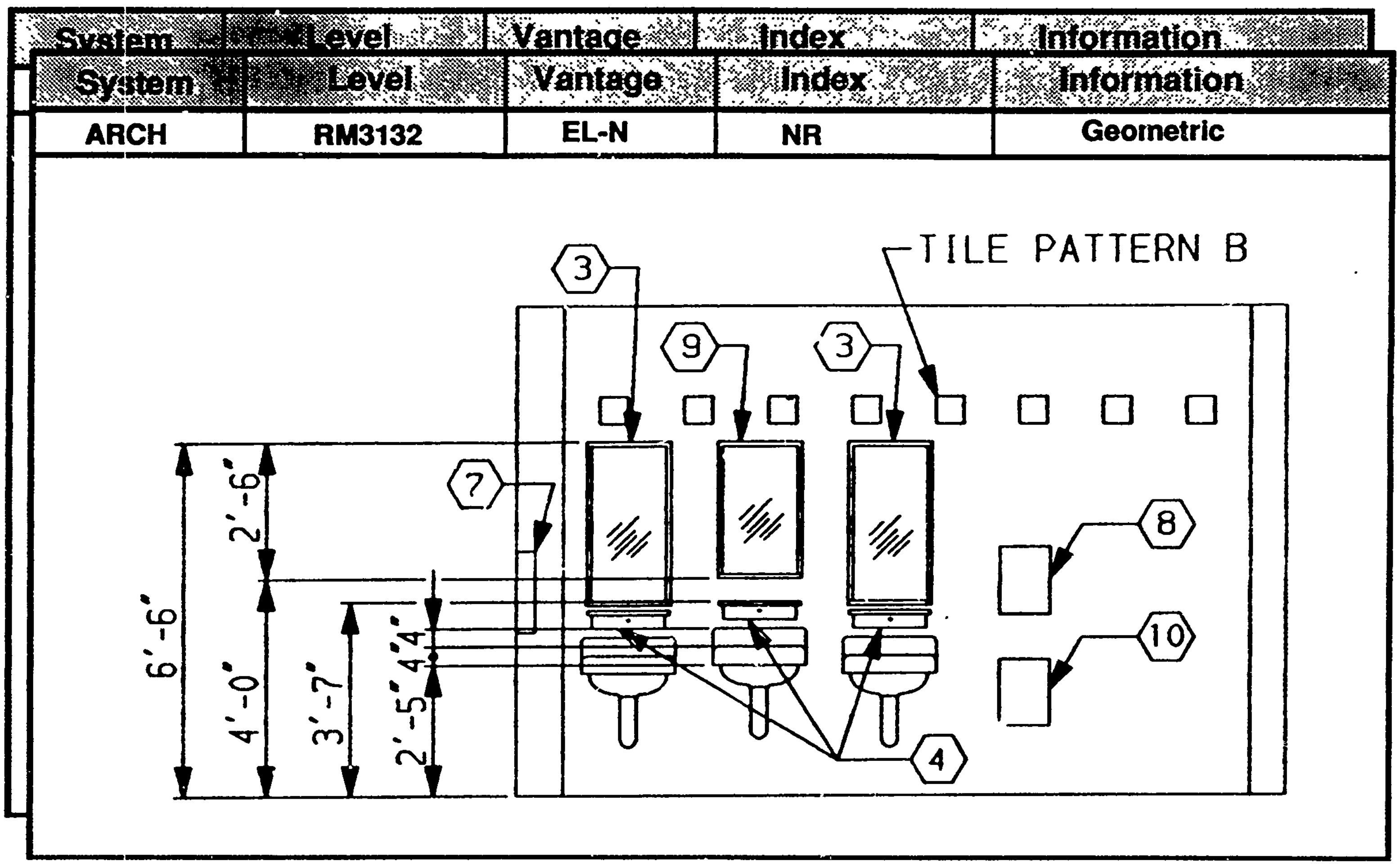


Figure 5.5: Example of Frame for Case 13: Room 3132, North Elevation

System	Level	Vantage	Index	Information
ARCH	COMP	NR	10800	Type/Style

ACCESSORY SCHEDULE	
KEY NO.	ITEM
1	GRAB BAR-HORIZONTAL
2	TOILET TISSUE HOLDER
3	MIRROR 1'-6"x3'-0"
4	SOAP DISPENSER W/ SHELF
5	MOP & BROOM HOLDER
6	SANITARY NAPKIN DISPOSAL
7	SANITARY NAPKIN-TAMPON VENDOR
8	PAPER TOWEL DISPENSER
9	MIRROR 1'-6"x2'-6"
10	WASTE RECEPTACLE
11	SHOWER ROD
12	SHOWER CURTAIN
13	TOWEL BAR
14	HOOKS
15	SOAP DISH
16	MIRROR

Figure 5.6: Example of Frame for Case 13: Accessory Schedule

Table 5.1: Case Study of FOIF on Fifteen Work Assignments

Problem/Drawings Used	FOIF Coding Structure					Does FOIF Describe Drawing? State exceptions.
	System	Level	Vantage	Index	Information	
Case 1: WA# 29 82138 Room 5109, Lock difficult to operate:						
A-6 5th Fl Plan	ARCH	RM5109	PLAN	NR	Geometric	Yes. Drawing shows whole floor.
A-40 Door Schedule	ARCH	COMP	NR	08100	Type/Style	Yes. Schedule shows other doors.
Hardware Schedule (specs)	ARCH	COMP	NR	08712	Type/Style	Yes. Schedule includes other hardware.
Case 2: WA# 29 78803 Room 4303, Drain is leaking:						
P-13 4th Fl Equipment Plan	PLMB	RM4303	PLAN	NR	Geometric	Yes. Drawing shows whole floor.
P-4 3rd Fl Plan	PLMB	FL3	RCEIL	NR	Geometric	Yes.
P-20 Waste & Vent Riser Diag.	PLMB	BLDG	NR	NR	Schematic	Yes.
Case 3: WA# 29 76596 Room 2311, Walk-in freezer leaking water:						
A-27 Partial 2nd Fl Equip Plan	ARCH	RM2311	PLAN	NR	Geometric	Yes. Drawing shows whole floor.
A-33 Equipment Schedule	ARCH	COMP	NR	11415	Type/Style	Yes. Schedule includes other equipment.
M-10 2nd Fl Piping Plan	MECH	RM2311	PLAN	NR	Geometric	Yes. Drawing shows whole floor.
Case 4: WA# 29 74184 Room 1211, Repair tagged light:						
E-5 1st Fl Lighting Plan	ELEC	RM1211	PLAN	16500	Geometric	Yes. Drawing shows whole floor.
E-5 Room Fixture Schedule	ELEC	RM1211	PLAN	16500	Type/Style	Yes. Schedule shows other rooms.
E-1 Lighting Fixture Schedule	ELEC	COMP	NR	16500	Type/Style	Yes. Schedule shows other fixtures.
Case 5: WA# 29 73214 Room 1204, Install wall brackets:						
A-2 First Floor Plan	ARCH	RM1204	PLAN	NR	Geometric	Yes. Drawing shows whole floor.
A 15 Interior Partition Sections	ARCH	RM1204	EL-E, S	NR	Geometric	Yes.

(Cont. on next page)

Table 5.1 (cont.)

Problem/Drawings Used	FOIF Coding Structure					Does FOIF Describe Drawing? State exceptions.
	System	Level	Vantage	Index	Information	
Case 6: WA# 28 85520 Room 5213, Water leak near receptacle:						
P-6 5th Fl Plumbing Plan	PLMB	FL5	RCEIL	NR	Geometric	Yes.
P-1 Plumbing Fixture Schedule	PLMB	COMP	NR	15450	Type/Style	Yes. Schedule includes other fixtures.
M-13 5th Fl Piping Plan	MECH	FL5	PLAN	NR	Geometric	Yes.
E-16 5th Fl Power Plan	ELEC	FL5	PLAN	NR	Geometric	Yes.
Case 7: WA# 29 85520 Room 1305, Fume hood not working:						
A-26 1st Fl Equipment Plan	ARCH	RM1305	PLAN	NR	Geometric	Yes. Drawing shows whole floor.
A-33 Equipment schedule	ARCH	COMP	NR	11610	Type/Style	Yes. Schedule includes other equipment.
Case 8: WA# 29 78731 Room 5305, Muddy water leaking from ceiling:						
P-7 Penthouse Plan (Plumbing)	PLMB	FL6	PLAN	NR	Geometric	Yes.
P-6 5th Fl Plumbing Plan	PLMB	RM531	PLAN	NR	Geometric	Yes. Drawing shows whole floor.
M-15 Penthouse Mech Plan	MECH	FL6	PLAN	NR	Geometric	Yes.
Case 9: WA# 28 67180 Room 1109, Check air control system:						
M-30 Mech Equip Schedule	MECH	BLDG	NR	15834	Type/Style	Yes. Schedule includes other AHUs.
M-16 Mech Rm Ductwork Plan	MECH	COMP	PLAN	15834	Geometric	Yes. Drawing shows whole floor.
M-24 Control Diagrams	MECH	COMP	NR	15900	Schematic	Yes.
Case 10: WA# 28 67065 Room 4212, Heat line leaking into one of the lights:						
M-12 4th Fl Piping Diagram	MECH	FL4	PLAN	NR	Geometric	Yes.
M-30 Equipment Schedule	MECH	RM4212	NR	15800	Type/Style	Yes. Schedule includes other equipment.
E-8 4th Fl Lighting Plan	ELEC	RM4212	PLAN	NR	Geometric	Yes. Drawing shows whole floor.

(Cont. on next page)

Table 5.1 (cont.)

Problem/Drawings Used	FOIF Coding Structure					Does FOIF Describe Drawing? State exceptions.
	System	Level	Vantage	Index	Information	
Case 11: WA# 28 56826 Room 4307, Convert fume hood 110V outlet to 208V, 20A duplex:						
A-29 4th Fl Equip Plan	ARCH	RM4307	PLAN	11610	Geometric	Yes. Drawing shows whole floor.
E-15 4th Fl Power Plan	ELEC	RM4307	PLAN	16400	Geometric	Yes. Drawing shows whole floor.
E-38 Panel PP4P Schedule	ELEC	COMP	NR	16472	Type/Style	Yes.
Case 12: WA# 27 84599 Check penthouse distilled water unit for contamination:						
P-7 Penthouse Plan	PLMB	FL6	PLAN	15400	Geometric	Yes.
P-12 Equipment detail	PLMB	COMP	NR	15404	Schematic	Yes.
Case 13: WA# 27 80066 Repair soap container in 3rd floor women's bathroom:						
A-4 3rd Fl Plan	ARCH	FL3	PLAN	NR	Geometric	Yes.
A-22 Enlarged Toilet Room Plan	ARCH	RM3132	PLAN	NR	Geometric	Yes. Typical plan of floors 2, 3, 4, 5.
A-22 Toilet Rm Elev; North	ARCH	RM3132	EL-N	NR	Geometric	Yes.
A-22 Accessory Schedule	ARCH	COMP	NR	10800	Type/Style	Yes.
Case 14: WA# 27 63526 Building fire alarm showing "trouble":						
E-29 Fire Alarm Riser Diagram	ELEC	BLDG	NR	16721	Schematic	Yes.
E-1 Legend & Fixture Schedule	ELEC	COMP	NR	16721	Type/Style	Yes. Schedule includes other fixtures.
Case 15: WA# 27 59122 Mount bulletin board in hallway, between rooms 3307 and 3309:						
A-4 3rd Floor Plan	ARCH	FL3	PLAN	NR	Geometric	Yes.
A-15 Interior Partition Sections	ARCH	RM327	EL-E, S	NR	Geometric	Yes. Shows typical cross section drawing.

(Case 14), a smoke detector is assumed to be faulty and the fixture schedule is listed.

5.5. Findings from the Case Study

Based on the case study several findings were made.

5.5.1. Need for More "System" Codes

The drawings used in the study decomposed the building functionally into greater detail than the FOIF's System code enabled. For example, the electrical system included separate drawings for power distribution (16400) and lighting (16500). The FOIF differentiated between the two with its Index code, which, similar to the System code, is based on UCI. It is felt that in actual application, the use of the System code to group common items would be preferred. For instance, upon facility acceptance, operators could define Systems to match the organizational structure of their various trades or shops (i.e. define a fire protection system if they had a separate fire protection system shop).

5.5.2. Multiple Coding Structures for the Same Item

Several drawings provided a wider scope of information than needed to locate the problem. Most commonly, the information needed was specific to an individual room while the greatest level of detail available in the drawings was the whole floor. Similarly, entire fixture schedules were listed when information was only needed about a specific schedule entry. Case 4 provides a good example. Figure 5.2 shows a room lighting fixture schedule for Rooms 1202 through 1214. The coding structure only "asked for" information about Room 1211. In this case, and many others, there was a "many-to-one" relationship between FOIF coding structures and the documents. Though the FOIF properly identified the desired information, these cases were noted in the last column of Table 5.1.

5.6. Discussion

In each of the fifteen cases considered, the item identified in the work assignment was successfully found using the facility documents. As shown in Table 5.1, the FOIF coding structure capably accessed each of the documents needed to find the same items within the building. Accordingly, two observations can be made:

1. The documents adequately described the location of each item spatially and functionally.

2. The FOIF can effectively describe the location of items within a building both spatially and functionally.

Given the location of an item in a building, the operator can then access the other information needed about the item by selecting it with the

FOIF Information code. Consequently, it can be concluded that the FOIF is effective in providing the operator with the information needed to operate the facility.

5.7. Summary

This chapter has demonstrated that the FOIF can be used to accurately describe the locations of items within a building. Fifteen work assignments from a representative building were studied. In each case, the FOIF successfully identified the documents needed to locate the items described in the work assignments. It was therefore concluded that the FOIF could be used effectively as a tool by the facility operator to access information about buildings.

Chapter 6

CONCLUSIONS

6.1. Overview

This final chapter compares the research conducted in the study with the original objectives. The FOIF's limitations are discussed and the areas for further research are identified.

6.2. Comparison of Research with Objectives

Chapter 1 stated a problem facing facility operators: the lack of a common framework for organizing and accessing the information required to operate a facility. This study set out four objectives for solving the problem. The four objectives and the research conducted to accomplish each are discussed below.

6.2.1. Defining Facility Operations and Information Organization

The first objective involved defining the role of the facility operator and identifying methods for organizing information used to describe facilities. This was achieved through a comprehensive review of the literature.

6.2.2. Identifying Facility Operator's Information Needs

The second objective entailed identifying the information about buildings most useful to the operator. By interviewing trade supervisors on the maintenance staff of a large university, numerous information needs were identified. These information needs were then organized in tabular format in Chapter 3 and show, for each major building material, component, or system, the information items required by the operator. Possible sources for that information are also identified. Subsequently, nine information categories were defined by consolidating the many specific information needs. These nine categories are useful when organizing building information by providing categories into which information items may be grouped. Figure 3.1 presented the nine categories and the many constituent types of information they represent.

6.2.3. Defining an Information Framework

The third objective was to define a simple, logical, and adaptable framework for organizing and accessing information used by the facility operator. Simplicity is achieved in the FOIF by:

1. Using only four codes to identify items in a building, both functionally and spatially.

2. Using the UCI system, widely recognized as the standard indexing code in the United States construction industry, as the basis for two of its codes.

3. Describing all operating information in terms of nine basic categories.

Each code defined in the FOIF is logical and straightforward. The codes are also adaptable to future changes in the AEC industry. In particular, the current trend towards the use of three-dimensional graphics is supported by the FOIF's Vantage code.

6.2.4. Testing the Framework

The final objective required testing the framework by using a case study application Fifteen work assignments from a representative building were used. For each one, the item described in the work assignment was located in the facility's documents and subsequently located using the FOIF. The ability of the FOIF coding structure to identify the drawings was noted. The FOIF was found to be generally effective, demonstrating that it can be used to locate items within a building.

6.3. Limitations of the FOIF

Several limitations of the FOIF are identified below:

1. The scope of the FOIF is narrow. Civil trades, furniture, manufacturing equipment, and moveable equipment were excluded from the study. The scope of the research was limited to a single owner and only buildings consisting of classrooms, offices, and laboratories were considered.

2. It only addresses the information needs of the facility operator. The facility operator, though responsible for the longest phase of the building's life, is but one player on the total facility team.

3. It does not define a mechanism for storing information so that it may be accessed in the manner described.

6.4. Areas for Further Research

Through the course of this study, and based upon the FOIF's limitations discussed in the previous section, several areas requiring further study were identified. A discussion of some of these areas is provided in the following sections.

6.4.1. Testing on Other Owners

The FOIF is limited in that it was developed and tested using a single owner. Additional owners should be selected and studied. Given the research presented in this study, the other owners could be asked to identify additional information needs, if any. Case studies, similar to the one discussed in Chapter 5. could be conducted to further test the FOIF.

6.4.2. Integration with the Other Life Cycle Phases

The information needs of the operator must be coordinated and integrated with those of planners, designers, contractors, and managers. The Information Framework for Project Developers already developed by Khayyal [1990] is an important first step towards this goal. The "Master Builder" approach of Khayyal's framework enables it to accommodate information from each phase of the life cycle. To support Khayyal's framework, specific information applied to the various life cycle phases must be identified. Under the Computer Integrated Construction Program at The

Pennsylvania State University, such research is ongoing. For example, planning information is currently being studied by Greg Perkinson. Given the specific information needs related to each phase, a fully integrated life cycle framework which addresses the specific needs of all players can then be developed.

6.4.3. Development of Standard System Codes

It was found from the case study (Chapter 5) that additional System codes would help to isolate information for the various trades responsible for operating the building. Three examples cited were power distribution, lighting, and fire protection. As an area for further research, a list of "standard" System codes which are aligned with the various trades of a representative owner's operations staff should be defined. For The Pennsylvania State University, the standard System codes might be defined as:

System (CODE)	UCI Divisions
Architectural (ARCH)	3 - 10, 12, and 14
Masonry/ Concrete	3 and 4
Carpentry	5 - 10
Roofs/ Exteriors	7
Locks & Hardware	8
Finishes	9
Elevators	14
Structural (STRU)	3 - 6

Plumbing (PLMB)	15: sections 15100 - 15500
Fire Protection	15: sections 15100, 15200, and 15500
Mechanical (MECH)	15: sections 15100, 15200, and 15600 - 15900
Heating & Refrig.	15: sections 15600 and 15650
Air Distribution	15: section 15800
HVAC Controls	15: section 15900
Electrical (ELEC)	16
Power Distribution	16: section 16400
Lighting	16: section 16500

6.4.4. Implementation of the FOIF

The FOIF still needs to be implemented. Implementation requires selection of an appropriate computer system and development or adaptation of the necessary software.

Implementation of the FOIF could have several benefits, which would be shared by tradesmen, trade supervisors, and trouble desk operators. The tradesmen could have on-line access to facility drawings and information **in the field**. For instance, given a pipe leak above a closed ceiling, the tradesman could conceivably access the piping drawings through a portable computer and determine, without disturbing the ceiling, what pipes are there. Trade supervisors would be able to better assign the proper work crews to each job by knowing the exact materials and systems involved with each work assignment. Copper pipe and fittings could be obtained to fix the water leak if it were known that all the pipes in the building were made of copper.

And finally, the trouble desk operator would be able to better visualize problems by **looking** at a representation of the building, floor, room, and even the component as a caller is describing its problem.

As a matter of practicality, it is possible that not all of the information items identified in Chapter 3 would be stored. The system might be used strictly for those items identified as time critical or items which are needed frequently. Users would have to decide upon the cost effectiveness for storing information based upon their individual needs and preferences.

As the FOIF gains popularity and acceptance, information standardization may become more prevalent. Owners may begin requiring designers and builders to organize facility operating documentation to meet the needs of the facility operations staff. For example, owners with an individual trade responsible for control systems may specify separate drawings showing a building's mechanical and electrical control systems. For their locksmith shop, they may specify a separate list of all door hardware. They may further specify that these documents be provided in a format which is most useful to them, such as in a commercial CAD or database application. With time, industry-wide standards may develop.

6.5. Summary and Conclusion

The FOIF is a simple, logical framework for organizing and storing the information needed by facility operators. It was demonstrated through a case study to be capable of describing the locations of items within a building. Consequently, it is also capable of providing the operator with the information needed about those items.

The system is based on current industry practices. It uses common terms, codes, and documents. It is also flexible. Though designed for the present, it is adaptable to future changes in the construction and computer industries.

It is impossible to predict the exact course of the construction industry or the extent of computer use in the process of providing a facility. Ideally, the ideas developed in this thesis will be of use in charting that course.

BIBLIOGRAPHY

Bigerson, B. "CBC/BCD as a National System." RIBA Journal, September, 1967, pp. 394-399.

Björk, B. C. "Basic Structure of a Proposed Building Product Model." Computer-aided Design, Vol. 21, No. 2, March, 1989, pp. 71-78.

Budeiri, M. Preparation of Work Breakdown Structures in the Construction Industry. Master's Thesis, The Pennsylvania State University, University Park, PA, December, 1984.

Carroll, C. R. "Facilities Management: Do Construction Documents Have a 2nd life?" The Construction Specifier, Vol. 39, No. 1, January, 1986.

Carroll, C. R. "Powerful Software Developments: How the Small Firm Can Benefit." The Construction Specifier, December, 1987, pp. 29-32.

Chung, Eun K. A Survey of Process Modelling Tools. Technical Report No. 7, CIC Research Program, Department of Architectural Engineering, The Pennsylvania State University, University Park, PA, 1989.

Cleland, David I. and King, William R. Project Management Handbook. New York: Van Nostrand, 1983.

CSI. Construction Documents and the Project Manual. Construction Specifications Institute Document MP-1-1. Washington, DC: The Institute, 1980.

CSI. Masterformat. Construction Specifications Institute Document MP-2-1. Washington, DC: The Institute, 1978.

DiPasquale, R. A. "Division 17: An Owner's Guide to Maintenance." The Construction Specifier, March, 1986, pp. 37-38.

Gielingh, Wim. "General AEC Reference Model." ISO TC 184/SC4/WG1 doc. 3.2.2., August, 1987.

Green, J. P. B. "Guide to SfB Building Filing Manual." RIBA Journal, May, 1966, pp. 208-213.

Guvenis, M. M. An Integrated Facility Operation Process Model. Technical Report No. 6, CIC Research Program, Department of Architectural Engineering, The Pennsylvania State University, University Park, PA, February,1989.

Hales, Lee. Computer-Aided Facilities Planning. New York: M. Dekker, 1984.

Hales, Lee. Computerized Facilities Planning. Atlanta, GA: Industrial Engineering and Management Press, 1985.

Hamer, Jeffery M. Facility Management Systems. New York: Van Nostrand, 1988.

Harvey, John. The Master Builders. New York: McGraw Hill, 1971.

Hetrick, M., and Khayyal, S. A. An Integrated Facility Construction Process Model. Technical Report No. 5, CIC Research Program, Department of Architectural Engineering, The Pennsylvania State University, University Park, PA, 1989.

Howard, H. C. et al. "Computer Integration: Reducing Fragmentation in the AEC Industry." Journal of Computing in Civil Engineering, Vol. 3, No. 1, January, 1989.

Humphries, J. B. "Measuring Maintenance Planning Success." Plant Engineering, Vol. 41, No. 19, October 8, 1987, pp. 60-64.

Khayyal, Sari A. Towards a Master Builder Information Framework for Project Developers. Technical Report No. 16, CIC Research Program, Department of Architectural Engineering, The Pennsylvania State University, University Park, PA, 1990.

Kitchens, F. et al. "Developing an Integrated Database." The Construction Specifier, August, 1987, pp. 120-123.

Magee, G. H. Facilities Maintenance Management. Kingston, MA: R. S. Means, 1988.

Martin, Douglas J. "Reference Model for Distribution Systems." ISO TC 184/SC4/WG1 doc. 4.2.1, Version 1.1, December, 1989.

Meredith, Jack R. and Mantel, Samuel J. Project Management. 2nd ed. New York: Wiley, 1989.

Meyer, Charles E. "Simplified Preventive Maintenance - The 'One-Minute' PM Manager." Ninth Annual International Facility Management Conference Proceedings, October, 1988.

Moncarz, P. D. "Designing for Maintainability." Civil Engineering, June, 1986, pp. 62-64.

National Research Council. The 1986 Workshop on Integrated Data Base Development for the Building Industry. Washington, DC: National Academy Press, 1987.

Peña et al. Problem Seeking - An Architectural Programming Primer. 3rd ed. Washington, DC: AIA Press, 1987.

Putkonen, E. A. "Facilitating the Transition from Construction to Operation by Use of Network Planning and Scheduling." Cost Engineering, Vol. 28, No. 2, February, 1986, pp. 26-31.

Sanvido, Victor E. An Integrated Building Process Model. Technical Report No. 1, CIC Research Program, Department of Architectural Engineering, The Pennsylvania State University, University Park, PA, 1990.

Smeallie, P. et al. "Developing an Integrated Database for the Construction Industry." The Construction Specifier, April, 1987, pp. 62-69.

Tomlingson. "Establishing a Maintenance Program That Works." Maintenance Technology, March, 1988, pp. 46-54.

Tompkins, James A. and White, John A. Facilities Planning. New York: Wiley, 1986.

Turner, James A. "AEC Building Systems Model." ISO TC 184/SC4/WG1 doc. 4.4, July, 1989.

Vanegas, Jorge. A Model for Design/Construction Integration During the Initial Phases of Design for Building Construction Projects. Ph.D. Thesis, Department of Civil Engineering, Stanford University, Palo Alto, CA, 1987.

Appendix A

INTERVIEW QUESTIONNAIRE

Jim Beckett
310 Sackett Building
865-3369

Thesis research questions:

What systems are you res~onsible for? (System and main components)

Which do you spend the most time on? (Most number of work assignments, most maintenance, etc.)

Which are the key systems? (Most urgent or expensive repairs)

Given a work assignment, what information do you:

look up most often? (from As builts, maintenance manuals, operation manuals, etc)

get **in person** by checking the site?

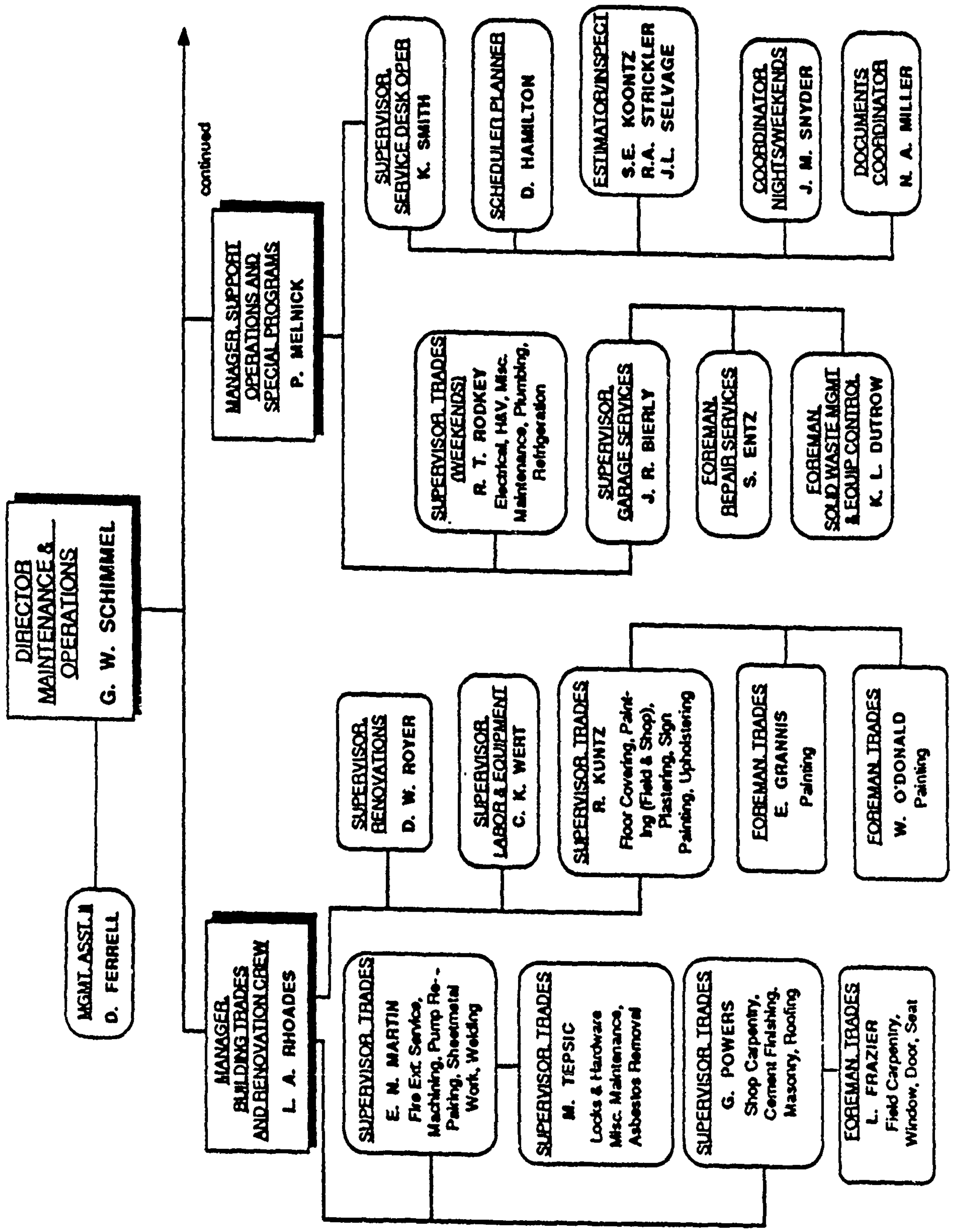
wish you had available to you?

consider the:

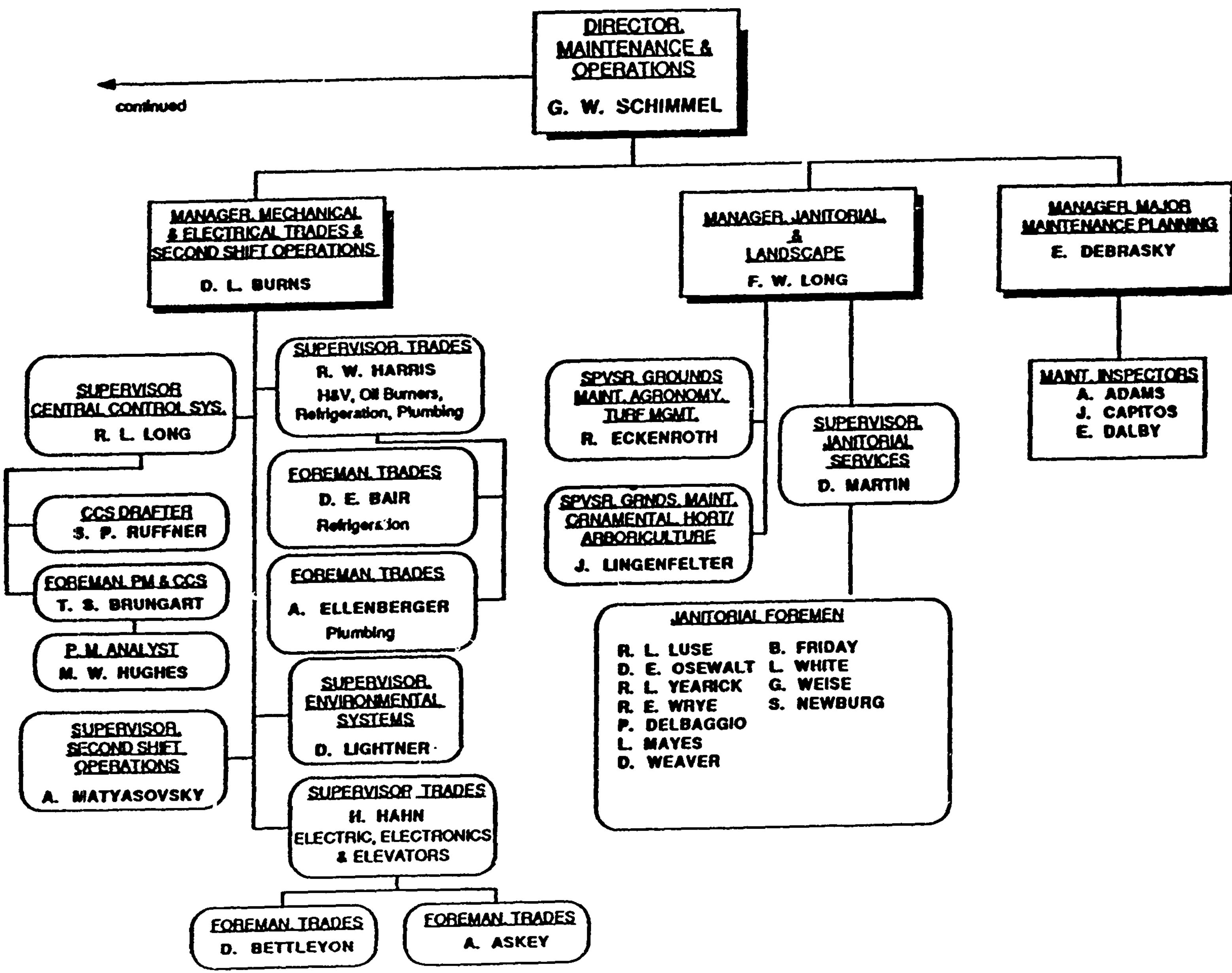
building as a whole
floor or system as a whole
individual room, pipe chase, service space, etc.
specific components.

Appendix B

MAINTENANCE AND OPERATIONS DIVISION ORGANIZATIONAL CHART



DIRECTOR MAINTENANCE & OPERATIONS
G. W. SCHIMMEL
MGMT. ASST. II
D. FERRELL
continued
MANAGER, BUILDING TRADES AND RENOVATION CREW
L. A. RHOADES
SUPERVISOR, TRADES
E. N. MARTIN
Fire Ext. Service, Machining, Pump Re-Pairing, Sheetmetal Work, Welding
SUPERVISOR, TRADES
M. TEPSIC
Locks & Hardware Misc. Maintenance, Asbestos Removal
SUPERVISOR, TRADES
G. POWERS
Shop Carpentry, Cement Finishing, Masonry, Roofing
FOREMAN, TRADES
L. FRAZIER
Field Carpentry, Window, Door, Seat
SUPERVISOR, RENOVATIONS
D. W. ROYER
SUPERVISOR, LABOR & EQUIPMENT
C. K. WERT
SUPERVISOR, TRADES
R. KUNTZ
Floor Covering, Painting (Field & Shop), Plastering, Sign Painting, Upholstering
FOREMAN, TRADES
E. GRANNIS
Painting
FOREMAN, TRADES
W. O'DONALD
Painting
MANAGER, SUPPORT OPERATIONS AND SPECIAL PROGRAMS
P. MELNICK
SUPERVISOR, TRADES (WEEKENDS)
R. T. RODKEY
Electrical, H&V, Misc. Maintenance, Plumbing, Refrigeration
SUPERVISOR, GARAGE SERVICES
J. R. BIERLY
FOREMAN, REPAIR SERVICES
S. ENTZ
FOREMAN, SOLID WASTE MGMT & EQUIP CONTROL
K. L. DUTROW
SUPERVISOR, SERVICE DESK OPER
K. SMITH
SCHEDULER PLANNER
D. HAMILTON
ESTIMATOR/INSPECT
S.E. KOONTZ
R.A. STRICKLER
J.L. SELVAGE
COORDINATOR, NIGHTS/WEEKENDS
J. M. SNYDER
DOCUMENTS COORDINATOR
N. A. MILLER


DIRECTOR, MAINTENANCE & OPERATIONS
G. W. SCHIMMEL
continued
MANAGER, MECHANICAL & ELECTRICAL TRADES & SECOND SHIFT OPERATIONS
D. L. BURNS
MANAGER, JANITORIAL & LANDSCAPE
F. W. LONG
MANAGER, MAJOR MAINTENANCE PLANNING
E. DEBRASKY
MAINT. INSPECTORS
A. ADAMS
J. CAPITOS
E. DALBY
SUPERVISOR CENTRAL CONTROL SYS.
R. L. LONG
CCS DRAFTER
S. P. RUFFNER
FOREMAN, PM & CCS
T. S. BRUNGART
P. M. ANALYST
M. W. HUGHES
SUPERVISOR, SECOND SHIFT OPERATIONS
A. MATYASOVSKY
SUPERVISOR, TRADES
R. W. HARRIS
H&V, Oil Burners, Refrigeration, Plumbing
FOREMAN, TRADES
D. E. BAIR
Refrigeration
FOREMAN, TRADES
A. ELLENBERGER
Plumbing
SUPERVISOR, ENVIRONMENTAL SYSTEMS
D. LIGHTNER
SUPERVISOR, TRADES
H. HAHN
ELECTRIC, ELECTRONICS & ELEVATORS
FOREMAN, TRADES
D. BETTLEYON
FOREMAN, TRADES
A. ASKEY
SPVSR. GROUNDS MAINT. AGRONOMY, TURF MGMT.
R. ECKENROTH
SPVSR. GRNDS. MAINT. ORNAMENTAL HORT/ ARBORICULTURE
J. LINGENFELTER
SUPERVISOR, JANITORIAL SERVICES
D. MARTIN
JANITORIAL FOREMEN
R. L. LUSE
D. E. OSEWALT
R. L. YEARICK
R. E. WRYE
P. DELBAGGIO
L. MAYES
D. WEAVER
B. FRIDAY
L. WHITE
G. WEISE
S. NEWBURG

Appendix C

SAMPLE INTERVIEW QUESTIONS AND RESPONSES

SAMPLE INTERVIEW QUESTIONS AND RESPONSES

Excerpt from interview with Mr. Ellenberger, Plumbing Trade Supervisor.

Q: What systems are you responsible for?

A: Supply, water treatment, waste, and fire systems.

Q: Which are the most important, or which ones do you spend the most time on?

A: Probably supply and distribution.

Q: What kinds of information do you need for them?

A: The type, first of all: Gas, steam, air, water.

Q: What else?

A: The location of the main valve. Our responsibility starts at the first valve inside the building.

Q: What kinds of information do you need inside the building?

A: As-builts, schematics, riser & vent diagrams, piping materials. Valve locations and what kind they are.

Q: Valve kinds?

A: Globe, gate, ball, OS & Y.

Q: The schematic diagrams and such - are they for the whole building?

A: Yes.

Q: How about valve locations and pipe materials?

A: A layout diagram of the floor showing materials, sizes, etc.

Q: How about information you wish you had, that you may not have currently?

A: Access panel locations. Most of these pipes and valves are behind walls and you can only get to them through access panels.

Q: What else?

A: I can't think of anything.

Q: What specific information needs do you have for the various systems, like gas, steam, etc.?

A: For gas distribution knowing, valve locations. For steam we need piping up to the fan coil or unit. Piping and valve locations are important. Component locations. Same with air.

Q: What else?

A: I can't think of anything.

[Similar line of questioning used for water treatment systems, plumbing fixtures, waste water systems, and sprinkler systems.]